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HANDBOOK OF PRACTICAL TELEGRAPHY.

A HANDBOOK

OF

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PRACTICAL TELEGRAPHY.

BY

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PREFACE TO THE FIFTH EDITION.

THE intention of the Author has been to give information to members of the Telegraph Service, and to those interested in Telegraphy, concerning—

The Electrical Laws upon which the system depends:
The Methods of discovering Faults:
The Practical Management of Apparatus:
The Construction of a Line:
And the Leading Principles of Submarine Telegraphy.

He has attempted to supply in some measure that technical knowledge which has hitherto been attainable only by means of verbal instruction or actual experience; and, with a view of rendering the work more acceptable to practical men, he has purposely avoided scientific terms and formulæ in the earlier portion of the work, and elsewhere when it has been possible to express his meaning without their use.

The Author thanks his friend Mr. Preece for his valuable help, and expresses his obligation to those members of his Staff who have so kindly and effectively assisted him.

He must also thank Mr. Chatterton, Mr. Willoughby-Smith, Mr. Latimer Clark, Mr. Forde, Mr. Hockin, Mr. Warren, Mr. Fleeming Jenkin, Mr. Varley, and Sir C. Wheatstone, for the information they have so courteously supplied.

LONDON, *May* 1871.

INTRODUCTION.

As the Telegraphs in Great Britain and Ireland have now passed into the hands of the State, a slight sketch of the history of the system in this country may not be out of place.

The Electric Telegraph was introduced by Cooke and Wheatstone, whose first joint patent was granted in 1837, in which year the earliest demonstration of the practicability of the system was made by the establishment of an experimental circuit between Euston and Camden Town, on the London and Birmingham Railway.

The first actual working telegraph was erected in 1838, between Paddington and West Drayton, on the Great Western Railway.

Cooke and Wheatstone's patents were purchased by the Electric and International Company, of which

Mr. John Lewis Ricardo was chairman; and in 1846 the Company was incorporated by Act of Parliament.

No assistance whatever was granted by the Government; and it was only after several years of adversity that the undertaking became firmly established.

In the first instance, the double needle instrument was used for the more important circuits, the single needle for the less important. The double needle was superseded, after a few years, by the chemical recording instrument of Alexander Bain; and eventually the Bain gave way to the Morse ink-writer, but the single needle held its place in consequence of the great ease with which it is kept in working order. Between London and Manchester, Glasgow, Edinburgh, and Newcastle, the Wheatstone automatic apparatus was used.

When the success of the telegraph had become established, other companies started.

The "Magnetic" Company was formed to introduce Henley's needle instrument, in which electricity was obtained from a permanent magnet instead of from a battery, but the manipulation of the magnet was found

to be too laborious, and it was abandoned for the battery. This needle instrument was superseded, for important circuits, by Bright's bell, which produces the signals of the single needle code by strokes upon two bells of different pitch, and has the great advantage over the needle that it leaves the hands free for writing the message as it is received.

Lastly, the "United Kingdom" Company was formed. This company used the Morse and Hughes only, and never employed the needle instrument.

Several of the railway companies transmitted messages for the public.

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HANDBOOK

OF

PRACTICAL TELEGRAPHY.

PART I.

SOURCES OF ELECTRICITY.

It has been customary to speak of electricity either as if it had a distinct existence, and were an infinitely subtle fluid capable of flowing as a current; or as if there were two fluids, opposite in their nature, capable of being separated from each other and held apart by certain processes, and which, in the act of recombining, produce the effects which are called *electrical*. These however, are mere theories, or assumptions for the purpose of simplifying explanation.

It is now considered to be a peculiar force, which causes the atoms or ultimate particles of matter to alter their position with respect to each other, or to become *polarized*, as it is called.

It is not necessary, however, in a practical handbook, to discuss questions which are simply hypothetical, nor to enter into those parts of electrical science which have not an immediate bearing on telegraphy.

1. When a dry glass tube, a stick of sealing-wax, or an ebonite comb, is rubbed on the coat sleeve, it attains the power of attract-

ing light substances. It is said to become *electrically excited*, and its electricity manifests itself in causing attraction. Electricity so produced is sometimes called *frictional electricity*.

2. If two narrow strips of very thin gutta-percha be laid side by side, and drawn quickly between the fingers, they will *repel* each other, but the excited glass tube will *attract* them. If a sheet of well-dried and warmed paper be vigorously rubbed with india-rubber and quickly cut into strips, the strips will repel one another when lifted from the table.

Upon this principle the *electroscope* (Fig. 1), an instrument for showing the presence of electricity, is made.

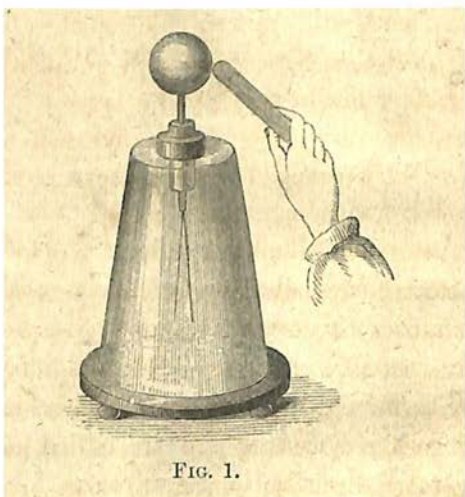

FIG. 1.

Gum two strips of gold leaf to the opposite sides of a thin piece of card; fix the card on a wire, taking care that the wire touches both the gold leaves; let it pass through a plug of sealing-wax or ebonite fixed in a hole in a glass shade (a glass flower-pot answers very well); screw a brass knob upon the wire, and place the glass shade on a stand.

Or suspend two balls of elder pith by dried sewing silk to a suitable support, so that they may hang side by side, a little apart. The silk will insulate the balls from each other, while the leaves of the first apparatus are in electrical contact.

3. Touch the knob of the gold-leaf electroscope with the *excited glass*, the leaves will diverge; they repel each other, in the same manner as the strips of gutta-percha.

Touch both the pith balls with the glass, they also repel; touch both with the finger, the repulsion ceases; touch both with the ebonite or sealing-wax, they again diverge: but touch one with the glass, the other with the ebonite or wax, they *attract* one another. They will also attract one another when only one of them is electrified.

4. It appears, then, that the condition or state of electrical excitation produced by rubbing glass, differs from that produced by rubbing ebonite or sealing-wax. The first is called "*positive*" or "*plus*," and is designated by the sign +; the second "*negative*" or "*minus*," and is designated by the sign −. These terms are entirely arbitrary; all that is meant by them is that the two states are *opposed* to each other, but not that there is more electricity in the one than in the other.

Bodies similarly electrified are said to have the *same sign*; if dissimilarly electrified, they are said to have *opposite signs*.

5. *Bodies similarly electrified, both +, or both −, repel. Those dissimilarly electrified, one +, the other −, attract.*

In order, then, to ascertain the *sign* of an electrified body, it appears only necessary to find whether it is attracted or repelled by an excited body whose *sign* is known. But as attraction occurs even when only one of the two bodies is electrified, it is better to find by trial which electricity will cause *repulsion*.

6. The two opposite states are always produced at the same time, and in exactly the same proportion—that is to say, when two substances are rubbed together they become oppositely or dissimilarly electrified, and to an equal degree; they therefore always attract one another. Thus, when ebonite is rubbed with cloth, the former becomes −, the latter +; when glass is rubbed with cloth, the glass becomes + and the cloth −; but when glass is rubbed with cat's fur, it becomes −, and the fur +.

Glass, then, does not always produce + electricity, nor, it may be, ebonite always −.

7. When the leaves of the gold-leaf electroscope are divergent, if the ball is touched with a body *similarly* but more strongly electrified the divergence will *increase.* But if the body is *dissimilarly* electrified, the divergence will *decrease.* If the quantity of the opposite electricities in the two is exactly equal, they will *neutralize* each other, and all signs of electricity will disappear.

8. A metal rod held in the hand and rubbed, will exhibit no sign of electricity; it will neither attract nor repel; nor will the cloth with which the ebonite or glass was rubbed, unless proper precaution be taken in each case.

9. *Some substances, such as metals and cloth, have the property of allowing electricity to diffuse itself freely throughout their whole substance, and are hence termed conductors.*

Others, such as glass and ebonite, offer very great resistance or opposition to this diffusion, and are called non-conductors, or insulators.

When a conductor is fixed upon or supported by a non-conductor, it is said to be insulated.

10. When the metal rod or the cloth is held in the hand and rubbed, the electricity produced by the friction immediately diffuses itself over its surface, over the body of the experimenter, and passes to the earth; so that the opposite tensions immediately neutralize one another, and the equilibrium or balance of electricity is restored without the exhibition of electrical phenomena: for metals, cloth, the human body, and the earth are *conductors.*

On the contrary, when the glass or ebonite is rubbed, the electricity does not diffuse itself or become neutralized, but remains where it was produced, manifesting its presence by causing attraction or repulsion; glass and ebonite being *non-conductors.*

But if the metal rod be *insulated* by being fixed on a glass

handle, and then rubbed, it repels or attracts; for now the electricity cannot escape, being confined to the rod by the insulating handle. In like manner, if the cloth be insulated by being held in a sheet of india-rubber, its electricity will manifest itself.

11. In order to deprive a non-conductor of the electricity excited on its surface, we must touch every part of it with the hand, or some other conductor. Whereas, a conductor can be deprived of its charge by touching one point of its surface only.

12. The division of substances into conductors and insulators is not absolute. There are few (if any) bodies which are perfect insulators, or which do not conduct *at all* under any circumstances; while even metals, the most perfect of all conductors, offer a certain *resistance* to the passage of electricity, or, in other words, insulate slightly. The terms imply a difference in degree only—good insulators are bad conductors, and good conductors bad insulators.

Each of the substances in the following table conducts better than that which precedes it; the first on the list is the best insulator, the last is the best conductor.

Dry air.	Wool.	Acids.
Ebonite.	Dry paper.	Charcoal or coke.
Paraffin.	Porcelain.	[1] Mercury.
Shellac.	Dry wood.	Lead.
India-rubber.	Dry ice.	Tin.
Gutta-percha.	Stone.	Iron.
Resin.	Pure water.	Platinum.
Sulphur.	Melting ice.	Zinc.
Sealing-wax.	Rarefied air.	Gold.
Glass.	Sea-water.	Copper.
Silk.	Saline solutions.	Silver.

[1] The order of conductibility is that of pure Metals, according to Matthiessen's most recent determinations. (Miller's Chemical Physics, 1867.)

Some descriptions of glass, if artificially dried, insulate better than gutta-percha.

13. The electrical machine is the most convenient apparatus for developing electricity by friction. It consists of a cylinder or plate of glass—or better, of ebonite—fixed upon an axis, and having *rubbers*, or cushions of leather stuffed with horsehair, so arranged as to press upon the glass and rub it when the axis is turned. An insulated metallic rod, or cylinder, collects the electricity from the glass, and is called the *prime conductor*.

Ebonite is better than glass, because it is less liable to break, and is not affected by damp. An ebonite machine must be very carefully protected from dust.

But for experiments connected with telegraphy, it is by no means necessary to employ so costly or so powerful a source of frictional electricity, an *electrophorus* being amply sufficient. (See par. 153.)

14. When an electrical machine of glass with an insulated rubber is set in motion, the rubber becomes negative, the glass positive, and they may be called the negative and positive *poles* of the machine. The glass communicates its positive electricity to the conductor, which then becomes the positive pole, and a pair of pith balls suspended from it will *repel* each other, while a ball suspended from the conductor will *attract* one suspended from the rubber. The force with which the balls are attracted or repelled, is directly proportional to the *tension* of the electricity present—that is, to its force or power of effecting a discharge or of overcoming resistance—and may be taken as a measure of this power. When ebonite is used instead of glass, the rubber becomes positive and the plate negative.

So long as the poles remain insulated the continued friction increases their tension, until it at last becomes so great as to cause a spark to pass between the two, restoring electric equilibrium. This is called an electric *discharge*.

Before the discharge, while the electricity is not in motion, it

is said to be in the *static*[1] condition; during the discharge it is in the *dynamic*[1] condition, because it then exercises force or power.

15. If the rubber and conductor are connected by a wire, no electrical effects are observed, because the two opposite tensions are instantly neutralized as soon as formed. If the wire is made very long and very thin, its conducting power will be lessened, and the neutralization will proceed more slowly. When the conducting power is still further reduced, as may conveniently be effected by using a piece of wet string instead of a wire, the neutralization will take place very gradually—as it were by a *current.*

16. *Whenever there exists a difference of tension (or potential) between two points connected by a conductor, a current passes between them until equilibrium is established.* The term *current* does not, however, imply the actual passage of any fluid or gas, but a simple transfer of force, an action which is progressive in its nature, like the passage of light through space, or of heat through a bar of metal. This action will be better understood further on, when *induction* has been studied.

17. There are many other methods of producing electricity, of which chemical action is the most important.

Electricity produced by chemical action is called *galvanic* or *voltaic,* from the names of its discoverers, Galvani and Volta. The apparatus for producing it is called a voltaic *pair* or *cell,* and consists of two conductors, generally metals, immersed in a liquid which acts, chemically, more upon one than upon the other. When several cells are connected together, the arrangement is called a *battery.*

Zinc is universally employed as one of the metals, and the greatest effect is obtained when the second metal of the pair is not acted upon at all by the liquid employed.

[1] The words *static* and *dynamic* are derived from the Greek: the one means *standing,* the other *power.*

For as the chemical action produces electrical tension, if it were possible for both metals to be attacked equally, there would be no difference of tension (or potential) between them, and consequently there would be no tendency towards a transfer of electricity; but if the chemical action be greater upon one than upon the other, the tension of the two will differ by an amount equal to the difference of chemical action, and as this difference increases so will the difference of tension increase. Therefore, when there is *no action* upon the second plate, the difference of tension is the greatest possible.

18. As voltaic electricity is produced whenever the conditions just mentioned are complied with, there are many different methods of making a battery. The *specific power* which each combination possesses of causing the transfer of electricity from one place to another, is called its *electromotive force*. This term, strictly, means *any cause whatever by which a difference of tension (or potential) is produced between any two points.*

19. In dilute sulphuric or nitric acid, the substances furthest apart in the following list form the most energetic combination:

Graphite (carbon from gas retorts).	
Platinum.	Lead.
Silver.	Tin.
Copper.	Zinc.
Iron.	

20. But as the power of evolving electricity depends on the difference of the chemical action upon the two plates, it will be altered by a change in the liquids employed: for instance, iron stands below copper when sulphuric acid or solution of common salt is used, while in ammonia the order is reversed.

21. So long as the two plates are not connected by a conductor exterior to the liquid, the electricity produced remains in the *static* condition, and, like frictional electricity, may be made to produce attraction and repulsion, so as to cause the gold

leaves of an electroscope to diverge. But the tension of voltaic electricity is feeble, so that unless a considerable number of cells are used a *condensing* electroscope (152) is necessary to produce the effect. The electroscope of Professor Sir W. Thomson is, however, sufficiently delicate to show attraction and repulsion where the tension is as feeble even as one-tenth of a Daniell cell, and that without the aid of a condenser.

22. When the plates are connected by a wire, or other conductor, the opposite tensions neutralize one another (10). But they are instantly restored by the chemical action, and are again as quickly destroyed. Thus a constant transfer or *current* is established, and the electricity is said to be in the *dynamic* state.

23. The + electricity is supposed to set out from the more oxidable metal, called the *positive* or *generating* plate, because it furnishes the supply of electricity; passes through the fluid to the less oxidable metal, called the *negative* or *collecting* plate, because it collects the electricity from the liquid; and thence by the connecting wire to the zinc again. But the end of a battery containing the *generating plate* (generally zinc) is called the *negative pole*, because it is there that the negative electricity is accumulated (the positive having passed into the liquid); while for a similar reason the last *collecting plate* is called the *positive pole*, since by it the positive electricity leaves the battery.

When zinc and copper are formed into a battery, the positive electricity passes from the zinc through the liquid to the copper, and from the copper to the conducting wire attached to it. (See Fig. 2.)

24. When two or more pairs of plates are so connected that the positive metal of the first is united by a metallic conductor to the negative metal of the second, and so on, the tension is increased in direct proportion to the number of pairs. Four pairs will have four times the tension of one pair, will produce a current capable of overcoming four times the resistance, and will diverge the electroscope four times as much.

25. Let the electromotive force of each *pair* of this battery of four cells be such as to produce a difference in tension between its *plates* equal to ten; the difference between its *poles* or end plates will be four times ten, or forty.

If both poles be *insulated*, the centre plates will be neutral; the zinc pole will have a – tension of 20, and the copper pole a + tension of 20. The one will be below, the other above, the tension of the earth.

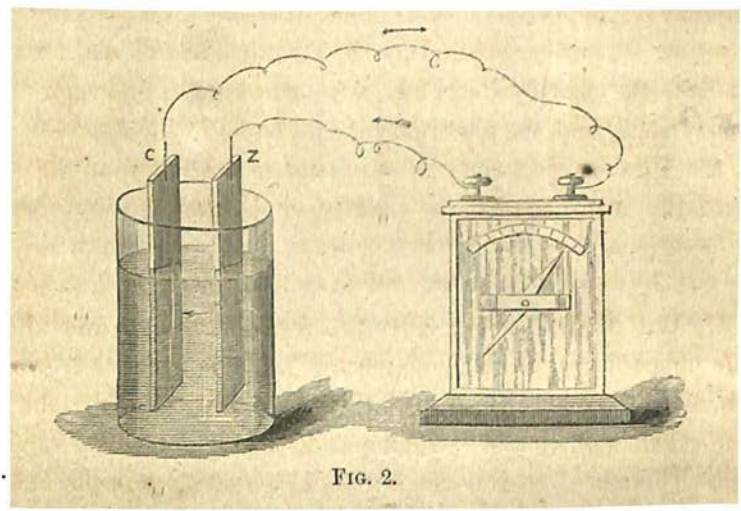

FIG. 2.

If either pole be connected with the earth, its tension will become that of the earth, that is, will fall or rise to zero. But as the electromotive force of the battery remains unaltered, the difference between its poles will still be 40, and the other pole will have a tension of 40 instead of 20, above or below that of the earth.

Suppose a copper and zinc pair in dilute sulphuric acid; let the difference of their tensions be ten.

If the copper of the first be connected to the zinc of a second similar pair, it will communicate to it its tension.

But as the difference between the plates of the second pair is also ten, and the second zinc has already a tension of ten, the

tension of the second copper will be 10 + 10 = 20, and so on. (See Fig. 3.)

26. Though the *tension* increases with every additional pair, no greater *quantity* of electricity will be produced with even a thousand pairs than with one pair; for the action in each cell is simply to urge forward a quantity equal to that arising from the oxidation or solution of the zinc of the first pair, not to produce more electricity.

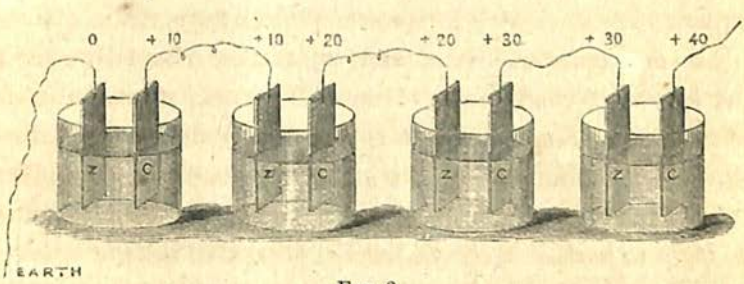

FIG. 3.

27. But if all the four zincs are joined together, and all the four coppers are similarly connected, so as to form, as it were, a pair of four times the surface, the *quantity* will be fourfold, but the *tension* will remain the same as with one pair of the original size. There will be four times *more* electricity produced, but its tension or power of overcoming resistance will be the same as that of one small pair, for the difference in the tension of its poles will be but ten. This subject is treated more fully in the chapter on the laws of the current.

28. As the number of cells is increased, the effects of the battery approach more and more closely those of the frictional (or electrical) machine, until, with 500 cells well insulated, attraction and repulsion may readily be shown without the aid of the condenser (152). By still further increasing the number, and carefully insulating them, the tension may be so far increased as to overcome the resistance of the air, and to produce a spark when the conducting wires are separated.

29. The electricities produced by the machine and the battery

are in fact identical, the difference between them being only this: the electricity of the former is high in *tension*, but the *quantity* generated is so small that no appreciable *current* can be *maintained* in a good conductor connecting its poles (15); while in the latter the tension is comparatively feeble, but the quantity is abundant enough, even from a very small pair of plates, to keep up a sensible current. The lowness of the tension of voltaic electricity renders the insulation of the conducting wire comparatively easy, while frictional electricity, from its great tension or power of overcoming resistance, passes by even the most imperfect conductors. Hence the earlier attempts in electric telegraphy, in which the machine was used, were failures, because the conducting wires could not be sufficiently insulated.

30. Faraday has calculated that a wire of platinum and one of zinc $\frac{1}{18}$th of an inch thick, immersed $\frac{5}{8}$ths of an inch in a mixture of one drop of acid to four ounces of water, will produce in three seconds as great a quantity of electricity as thirty turns of a 50-inch plate machine. Voltaic electricity has been compared to steam rising quietly from an open boiler, while frictional electricity is the high-pressure steam of a locomotive. Lightning is the spark or discharge of electricity of very high tension.

31. Although chemical action is the cause of electromotive force, such action may take place in the cells of the battery without adding to the strength of the current, for if a small piece of iron or copper, for instance, touches the zinc plate, voltaic action will be set up between them; while the neutralization of the tensions will take place upon the surface of the metal instead of through the connecting wire, so that the zinc is wasted. This is called *local action*, and the greatest care must be taken to prevent it.

32. When copper, *pure* zinc, and dilute sulphuric acid are formed into a battery, there is no action so long as the poles are disconnected; but if ordinary zinc is used, bubbles of hydrogen are given off from its surface immediately it is placed in the acid,

even if there be no copper plate in the liquid. The evolution of hydrogen arises from the *local action* caused by the particles of lead, carbon, iron, and other impurities contained in the metal, which being negative to zinc form small batteries on the surface of the plate, dissolving it away in holes without producing any useful effect. When old zinc plates are recast, the impurity of the metal is increased, for, besides the foreign matters it originally contained, there will be found particles of copper which have been deposited on the plates while in action. The metal at the bottom of the crucible will be the most impure.

33. Pure zinc is very rare and expensive, and therefore cannot be used; but by the process of *amalgamation* common zinc is rendered equally serviceable. The simplest way to amalgamate zinc is to clean it by dipping it into dilute sulphuric acid; then place the plate in a shallow dish containing a little dilute sulphuric acid, and pour a small quantity of mercury upon it, rubbing the mercury over the surface with a piece of rag tied round the end of a stick, keeping the rag well wetted with the acid. A small strip of zinc is sometimes useful to collect the mercury from the dish and place it on the plate. The mercury dissolves a little zinc, which flows over and covers the foreign particles, preventing their contact with the acid.

34. When the poles of a battery are united by a conductor, a current is established, the water in the cells is decomposed, or separated into its component gases; the oxygen is set free at the zinc plate and combines with it, forming oxide of zinc, which the acid immediately dissolves, converting it into sulphate.

The hydrogen is set free at the copper plate, and escapes in bubbles; but hydrogen in this particular condition, called its *nascent state*, has the power of separating metals from their solutions, so that as soon as the sulphate of zinc dissolved in the water has so far diffused itself through the liquid as to reach the copper plate, it is decomposed by the hydrogen, coating the copper plate with zinc. This action tends to con-

vert the battery into one in which zinc is eventually opposed to zinc, and therefore reduces, and finally destroys, its force.

Again, a portion of the hydrogen adheres to the copper, acting upon it as if it were a liquid (20). But as copper excited by hydrogen takes up an opposite tension to copper excited by sulphuric acid in the presence of zinc, the power of the battery is lessened. The copper plate is said to have become *polarized.*[1]

35. To render a battery *constant*—that is, uniform and lasting in its action—polarization and deposit of positive metal upon the negative plate must be prevented. This is best effected by surrounding the negative plate by a strong solution of a salt of the metal itself, because then the hydrogen will not escape or cover the plate, but will be solely employed in reducing metal from its solution; and as the reduced metal is the same as that of which the plate itself is composed, the battery, instead of losing, will gain, because the negative plate will be kept constantly clean and bright by the new metal deposit upon it.

36. The *Daniell Battery,* in great measure, fulfils these conditions. It consists of a cell or jar containing a cylinder of amalgamated zinc, and a cell of porous earthenware, smaller than the zinc cylinder and fitting inside it. The *porous cell,* as it is technically called, contains a plate or cylinder of copper, and is filled with a solution of sulphate of copper, while the outer jar is filled with dilute sulphuric acid. So long as the zinc and the copper are not connected by a conductor there is no chemical action, for the acid does not act on amalgamated or on pure zinc (33), nor the sulphate of copper on the copper; but the moment the circuit is closed—that is, as soon as a communication is established between the two metals—the zinc is strongly attacked, but no hydrogen

[1] The term "polarized" is here used in a sense somewhat differing from that which it ordinarily bears.

is given off at its surface, as there is no local action. Water is decomposed, oxide of zinc is formed, which the acid dissolves, forming sulphate of zinc. The hydrogen passes to the copper, but instead of escaping at its surface, adhering to it and *polarizing* it (34), it decomposes a portion of the sulphate of copper, precipitating copper upon the copper plate, keeping it clean and bright.

The acid of the sulphate of copper passes to the zinc, assisting the sulphuric acid already there to dissolve it and form sulphate of zinc. The only use of the acid originally placed in the zinc cell is to make the fluid round the zinc a better conductor; and when a large quantity of electricity is required, the sulphate of copper is also acidulated with half its bulk of strong sulphuric acid. The action of the battery is therefore to form sulphate of zinc in the zinc cell, and to consume sulphate of copper in the copper cell, the zinc being constantly dissolved away while the copper plate is increased.

When the action of the battery has decomposed all the sulphate of copper, the action ceases; and if any sulphate of zinc has passed into the copper cell, as will generally be the case, zinc will be reduced upon the copper plate as a black powder. It is necessary, therefore, to provide a constant supply of sulphate of copper, which should be placed at the bottom of the cell for long-continued action, but at the upper part of the cell when energetic action is required, as it then dissolves more regularly and quickly.

37. When the acid in the zinc cell becomes saturated with zinc, the battery, though less powerful, will be more constant than when excited by acid.

A solution of sulphate of zinc may therefore be used in the zinc cell in place of sulphuric acid, and it will not then be necessary to amalgamate the zinc plate, as there will be little or no local action (32).

When continued action is required, mercury is positively in-

jurious, because the metallic copper which is deposited on the zinc plate (41) forms an amalgam with the mercury, which very greatly impedes the action of the battery, far more so than when deposited on unamalgamated zinc.

38. Should the water become saturated with sulphate of zinc (*i.e.* contain as much as it can dissolve), the sulphate crystallizes upon the zinc plate, stopping the action of the battery. The conducting power of a solution of sulphate of zinc is greatest when diluted with an equal quantity of water. Part of the solution should, therefore, be from time to time removed and replaced by water (82).

39. If the porous cell be of bad quality, containing coke or metal dust, the copper will be deposited in patches upon it. When these patches of copper touch the zinc, they form local circuits, like the particles of foreign matter contained in the zinc itself (32), wasting both sulphate of copper and zinc. When the porous cell becomes crusted with copper, it should be removed.

40. The zinc should never be allowed to touch the porous cell, for copper will immediately be deposited on the porous material, and thus form a local circuit with the zinc.

41. Porous cells but very imperfectly prevent the mixing of the liquids. The liquid passes through the porous cell from the zinc to the copper in virtue of a singular property common to all porous substances when dividing dissimilar liquids, called "osmose," and it will frequently rise in the copper cell an inch or more above the level. The current aids this movement. The copper solution passes into the zinc cell, and is decomposed by the zinc plate. The sulphuric acid of the sulphate of copper leaves the copper, dissolves the zinc, for which it has a greater chemical *affinity*, and copper is deposited, in a metallic form or as a black spongy mass, upon the zinc plate, or falls to the bottom of the cell. When the cells are very porous, as much zinc is dissolved and sulphate of copper used when the battery is idle as when it is at

work. The zinc plates should be frequently scraped to remove the deposit, which is very valuable, and should be carefully preserved.

42. The chemical action of zinc upon sulphate of copper is well shown by suspending a piece of the metal in a weak solution of the salt: the zinc will be covered with metallic copper in a few minutes, and in a short time the whole of the copper will be removed from the solution and replaced by zinc. By this means the copper contained in the waste zinc solution may be removed, and the liquid fitted for charging fresh troughs.

43. The zinc cell should be much larger than that containing the copper, in order that the sulphate of copper which leaks through may have more liquid into which to diffuse itself, and thus become more dilute; the zinc will then act on it less rapidly. The copper cell should be a little taller than the zinc, so that it may not overflow. The porous cells of a battery intended only for occasional use should be somewhat thicker than those of one constantly in action; for the loss of power due to the extra thickness of the porous material (83) is more than compensated by the diminished waste of sulphate of copper, caused by the obstacle which the thicker cell presents to the mixing of the solutions. If a separate porous cell is used, its back, sides, top, and bottom should be dipped in good hard melted tallow or paraffin, to prevent the solution passing through those parts that do not face the zinc.

44. If the several cells of a trough leak into each other, the action of the cells will be increased, but the effective current will be reduced by the formation of "short circuits." The same happens in some measure when the sides of a trough are wet, or encrusted with salts.

45. A defective cell, arising from a leakage or a broken porous partition, is sometimes found, reducing the power of the whole battery. In such a case it is a good plan to bridge it over thus:—thoroughly clean the straps of the two battery plates

between which the defect lies, and connect them across by a piece of wire.

46. When the water has become charged with the sulphate of zinc produced by the action of the battery, crystals form on the sides of the cell; the liquid passes up between them and the sides, crystallizing again above, until at last the crystals pass over the edge, and form a kind of syphon, which draws off the liquid, especially when the trough is made of gutta-percha, which is an unsuitable material for the purpose. This may, in great measure, be prevented by painting the edge of the cells with solid paraffin, dissolved in warm paraffin oil. Porcelain cells may be dipped in the mixture about half an inch, after having been well dried. The crystals should be occasionally removed with a damp cloth.

47. In consequence of the tendency of the solutions to mix through the porous cell, a battery has been contrived in which the solutions are separated by their respective weights alone. The copper solution being heavier than the zinc, the copper plate and crystals of sulphate of copper are placed at the bottom, the zinc plate being hung perpendicularly near the top of the cell, which is filled with a dilute solution of sulphate of zinc.

In this battery, called the "gravity" battery, the cells should not be quite filled with crystals, for when the level of the copper solution is raised to the zinc plate, the zinc reduces the copper from the solution. It is a very common and a very wasteful process to put in as much sulphate as the cell will hold.

When the plates are placed vertically, the two metals should never face or cross each other, but the upper edge of the copper should be level with, or rather below, the lower edge of the zinc. If the zinc be below the upper edge of the copper, it will remove all the metal from the sulphate of copper solution as far as the zinc plate reaches, and it will therefore leave none to act upon that part of the copper plate which faces the zinc. The sulphate of copper should be so placed as to dissolve only just

as fast as it is used up by the action of the battery, for although its solution is heavier than the solution of zinc in the upper part of the vessel, the two will certainly mix after a few days, in accordance with the laws of the diffusion of liquids.

This battery has been very extensively used, but the extra care required in managing it more than counterbalances its advantages; absolute rest is essential to its constancy and durability.

48. For common use, the following is a good and economical battery. It is a modified Daniell. A teak trough, with a lid, is divided into cells by plates of glass or slate, and well coated with marine glue. The cells are subdivided by a slab of porous porcelain, $\frac{1}{4}$-inch thick. The plates are cast zinc, 4 inches $\times$ 2 inches, and thin copper, 4 inches square. A copper strap is cast into the zinc and riveted to the copper plate: the end which is cast into the zinc is previously tinned to ensure contact. The zinc hangs at the upper part of the cell, which is filled with dilute solution of sulphate of zinc. The copper cell is filled with a saturated solution of sulphate of copper, and crystals of this salt, as large as a small hazel-nut, are placed at the bottom. This battery has been adopted by the Post Office. The expenditure in sulphate of copper is about 1·45 lb. per cell per annum.

Several other modifications of the Daniell have been employed; among the most important is the so-called

49. *Minotto Battery.*—This battery consists of a glass jar, at the bottom of which lies a disc of copper soldered to a wire, covered with varnish or percha, which extends to the top of the jar. Above the disc is a layer of coarsely powdered sulphate of copper, covered with a layer of clean sand; the sulphate and the sand are separated by a disc of cloth or porous paper. The jar is nearly filled with soft water, and a piece of unamalgamated zinc, sufficiently large to last as long as the sulphate of copper, is laid upon the surface of the sand. The wire connected to the zinc must be so arranged as to allow it to follow the sand as it is

lowered in the jar by the gradual solution of the sulphate of copper.

Sawdust is sometimes used instead of sand, and in some cases a glass tube passes through the centre of the sand or sawdust, by which fresh sulphate can be added.

Gas is frequently given off on the surface of the zinc, which covers the metal so as to protect it from the liquid, and causes polarization. If the plates be cast wedged-shaped and hung with the edge downwards, the gas passes away more freely. This action of the gas renders the current somewhat unsteady, especially when it is used for delicate experiments. So far as the author's experience is concerned, it is not well adapted for the service of a busy circuit.

50. *Graphite Battery.*—The following is the best form of graphite, or gas carbon battery, with amalgamated zinc and dilute sulphuric acid, 1 part to 12 of water.

The carbon plates are pickled a few days in strong sulphuric acid and water, drilled and electrotyped[1] with copper at their top; this copper is then tinned, the connecting strap is riveted to it with tinned rivets and then soldered. The carbon is then platinized by the electrotype process, using a straw-coloured solution of platinum, with a battery of 4 cells. A small slipper of percha is fixed to the bottom of the zinc plate, to contain a little mercury for the purpose of maintaining the amalgamation by capillary action.

When the jar is considerably deeper than the plates, so that the solution of sulphate of zinc can fall to the bottom as it forms, leaving the lighter acid at the top, this battery lasts a long time. It is, however, not suited for producing a continued current.

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[1] To Electrotype.—Place the part of the carbon plate to be coppered in a saturated solution of sulphate of copper, connect it to the zinc of a single Daniell cell, place a copper plate in the solution so as not to touch the carbon, and connect it to the copper of the cell.

51. *Sand Battery.*—Amalgamated zinc and copper, placed in a cell filled with pure, sharp sand, moistened with dilute sulphuric acid (one of acid to twelve of water), form a convenient portable battery. When the battery is not in use the acid dissolves a little copper, which is again deposited on the plate when the battery is worked.

Care must be taken that the sand is quite free from iron, lime, or other impurities, and that the water is freed from lime. The acid and water should, therefore, be mixed before it is wanted, when the lime will fall down in a white powder. Lime encrusts the zinc, and spoils the battery.

There is very little room for liquid, so that, if in constant action, the sand soon becomes choked with sulphate of zinc. This can be removed by soaking the trough in water, and draining it carefully.

52. *Modified Smee Battery.*—Scraps of zinc are laid in a saucer containing mercury, placed at the bottom of a glass jar, and a plate of platinized silver (silver coated with platinum by the electrotype process) is hung vertically above. The jar is filled with dilute sulphuric acid.

It needs rest after each signal, because the sulphate of zinc formed by its action forms a stratum over the zinc saucer, protecting it for a time from the action of the acid. A piece of percha-covered wire, bared for a $\frac{1}{4}$-inch, dipping into the mercury, forms the zinc connection.

53. The *Leclanché Battery*, which has been recently introduced, consists of a zinc rod placed in a solution of the ordinary commercial sal-ammoniac (chloride of ammonium); the negative plate is a piece of carbon surrounded by a mixture of gas carbon and the *needle form* of peroxide of manganese contained in a porous jar. Both the manganese and carbon must be broken in small pieces, and sifted to remove the dust, as the presence of fine powder interferes with its action. The action of this battery is to form zinc chloride, which is soluble in sal-ammoniac; the

peroxide of manganese is reduced to a lower oxide, and ammonia is formed in small quantities. Thus, after an interval of time, generally twelve months, the zinc and peroxide must be replaced and the sal-ammoniac renewed. In practice, for every 50 grains of zinc dissolved 100 grains of sal-ammoniac are consumed, and 100 grains of peroxide of manganese are reduced. The electromotive force of this battery is very great. It is equal to about 1·6 of a Daniell cell, so that 10 Leclanché cells are equal to 16 of Daniell.[1] The internal resistance is also very much less than that of a Daniell cell, and therefore its "quantity" considerably greater; but, on the other hand, when placed in short circuit it polarizes very quickly, so that it cannot be used for permanent currents or as a local battery.

There is no waste of material when the battery is not in action, so that, if the evaporation of the liquid is prevented, it may be allowed to remain untouched for months without losing power. It is therefore more suitable than the Daniell where constant attention cannot be provided, and where the telegraph is not in constant use; and for electric bells. Several points need attention in the setting up of this battery. The carbon plates are capped with lead, in order to provide an attachment for the binding screws, for copper would be attacked by the ammonia. But it is found that a salt of lead is formed between the carbon and the metal, which in time insulates them from each other. To prevent this, the carbons are first well dried and heated to about 120° Centigrade, their tops are then dipped in melted paraffin and covered with lead, great care being taken to press the lead closely into contact with the carbon.

[1] Other trials with new batteries have given even a more favourable comparison, the electromotive force as shown by a Thomson electrometer being as 25 to 40, and the strength of signal through resistance as 27 to 40. But while the Daniell was capable of affording a steady constant current on a circuit of very small resistance, the Leclanché fell from 60 to 35 in half a minute. But with a higher resistance the current was steady. The electromotive force of the Leclanché as compared with the Minotto are as 160 to 300.

It is not absolutely necessary to amalgamate the zinc, but the amalgamation tends to prevent the formation of crystals upon its surface. When the sal-ammoniac has nearly been removed from the liquid, it is unable to dissolve the chloride of zinc, and in consequence becomes milky; more ammonia salt must then be added. When the battery begins to fail, the porous jars may be soaked in water, but this process cannot be adopted a second time. The cell should not be filled above two-thirds of its depth. There has been no very large experience of this battery, but it bids fair to become of great importance.

54. The *Marie-Davy Battery*, constructed with zinc, carbon, and a solution of the white crystalline bisulphate of mercury, was till lately almost exclusively employed at the Central Office of the French Administration of Telegraphs in Paris. It is a very powerful battery, and produces excellent effects, but its maintenance is expensive, and it is not adapted for continuous work, owing to the slow solubility of the salt. It is self-amalgamating, and, owing to the high conducting power of the solution, its quantity is very considerable—or, to speak more correctly, its resistance is very small, while its tension is such that 8 of its cells are equal to 12 of Daniell's.

Ordinary single fluid batteries, owing chiefly to polarization, do not produce constant currents for two minutes together, and they are only adapted for the production of momentary effects, such as the sounding of gongs, ringing of bells, firing fuses, or dropping time signals.

55. The batteries of Grove and Bunsen are not used in England for telegraphic purposes; they have been tried on the Continent, but in almost every place have given way for the Daniell, the Marie-Davy, or the Leclanché.

56. *Secondary Batteries.*—Polarization (34, 35) is employed in some cases to produce a powerful but transient current. The principle is well shown in Grove's "Gas Battery." Two strips of platinum are placed side by side in acidulated water, and are

connected to the two poles of a battery sufficiently powerful to decompose water (34): this is called the *primary* battery. Oxygen is given off upon one of the strips, hydrogen upon the other, and as neither hydrogen nor oxygen have an affinity for platinum, both gases remain upon their respective metal plates, forming, when the primary battery is removed, a so-called *secondary* battery of platinum in oxygen opposed to platinum in hydrogen, the current resulting from which will be in the opposite direction to that of the primary or decomposing battery.

57. Lead, or any other metal with but a slight affinity for oxygen, may be used instead of platinum; and in practice, a number of plates of the same metal, usually thin sheet-lead, are arranged in series as a battery in cells, filled with dilute sulphuric acid, or with sawdust moistened with dilute acid. When a current from another battery is made to pass through it, water is decomposed, its oxygen forms peroxide of lead, coating the plates on one side of each cell, while its hydrogen spreads over the opposite plates, polarizing the lead plates, and forming a battery of lead with hydrogen, and lead with peroxide of lead. When the primary battery is removed, and the poles of the secondary battery are connected, the action of these products causes a current in a reverse direction to that of the primary battery. The duration of this *secondary* current depends, within certain limits, upon that of the primary.

58. A zinc-carbon battery upon this principle is used for distributing the time signals from the central station of the Postal Telegraphs. Each *alternate* partition of a gutta-percha trough, divided into cells, is cut down to within about half an inch of the bottom, and the two divisions thus formed are filled with mercury, care being taken that the two portions of mercury do not touch. Small pieces of zinc are placed in one portion, and a plate of graphite (gas carbon) in the other, as the two plates of a battery; and the cell is filled with dilute sulphuric acid. The necessary connection between one cell and another is formed by

platinum wire passing through the percha into the mercury. To excite it, it is connected, carbon to copper and zinc to zinc, with a battery of about twice the number of cells for about half an hour. This arrangement produces a very energetic current for a few seconds, and will give an effective signal upon ten or more long circuits.

59. When there is no local action, *the amount of decomposition in each and every cell of a battery is equal.*

That is to say, if in one cell of a series of 100, one ounce of sulphate of copper is decomposed, exactly one ounce will be decomposed in each of the other 99.

60. When a battery is in good condition, each cell produces by its own action the requisite decomposition; but if a cell is weak, it must be assisted, as it were, by the rest; so that instead of adding to the force of the battery it diminishes it. As old batteries contain exhausted charges and foul plates, they should never be placed in series with new ones.

61. If all the cells are not alike in size, or if the plates in some are smaller than those in others, the smaller will be first exhausted. When a pair is *reversed,* joined copper to copper instead of copper to zinc, its solutions are not only decomposed by the remaining cells, but the latter must also overcome the electromotive force of the reversed cell, which is obviously contrary to that of the battery. If in a series of four cells one be reversed, it will nearly neutralize the effect of the remaining three.

62. In a Daniell battery, the action of the current deposits on the copper plate one *equivalent* or 25 parts of metallic copper for each *equivalent* or 26 parts of zinc dissolved. As sulphate of copper contains 25·5 per cent. of metal, for every 100 ounces of sulphate decomposed 25·5 ounces of copper are deposited, and 26 ounces of zinc dissolved. The same law applies to the decomposition of that portion of sulphate of copper which penetrates the zinc cell, and, attacking the zinc

plate *locally*, forms the deposit which falls to the bottom of the cell.

63. In setting up a Daniell battery the following precautions are necessary:—The crystals of sulphate of copper should be the size of a hazel-nut; they should not be crushed so as to reduce them in part to powder, for they then form a compact mass, which dissolves so slowly as to be almost useless, and cannot be removed without danger of breaking the cell.

64. The copper connecting-straps, wires, and binding-screws must be perfectly clean. The end of the strap which is cast into the zinc should be tinned to ensure perfect contact.

The plates should be alike in size, and immersed equally in the liquid. The coppers should be carefully brightened, and the zincs brushed clean. Copper plates, if very dirty, may be cleaned by being made red-hot and dipped into weak ammonia. A piece of the "card" used in cotton manufactories is the best brush for battery plates.

65. If the water contains lime, it decomposes a part of the sulphate, forming a cloudy or jelly-like deposit. To prevent this, a few drops of dilute sulphuric acid should be added. The copper cells should be charged with saturated solution of sulphate of copper before any liquid is poured into the zinc cells, so that the pores of the porous divisions may be filled with a *good conductor*, for otherwise the action of the battery will be checked.

When the zinc cells of a battery are charged with water only, it rarely assumes its full power until it has been at work for two or three days; but it can immediately be set in full action by the addition of solution of sulphate of zinc, provided the porous cells or divisions are well saturated with the copper solution.

66. It is false economy to work Daniell batteries after the zinc or the porous cells have become coated with copper, or to use cracked porous cells.

67. When a battery is cleaned the plates should be removed, and the divisions thoroughly rinsed and washed out, the plates well scraped and scrubbed, defective porous cells and zinc plates removed, and the battery again carefully charged.

In re-charging the battery, the liquid from the zinc cells may be used. It may be withdrawn by a syringe before the battery is cleaned, and (42) placed in a vessel containing a few pieces of zinc to reduce any copper that may remain in solution. When the battery has been cleansed, the plates replaced, and the sulphate of copper deposited in the cells, the solution may be distributed equally throughout the zinc cells—diluted, if necessary (72).

68. Batteries must be kept in a dry place, and be *well insulated*, or part of the current will escape to the earth. If too warm, the water will evaporate. Cold stops their action, so that they must never be placed where they are not perfectly secure from frost.

69. Porous cells, or troughs fitted with porous plates, if set aside after they have been used, must be kept moist, or the sulphate of zinc contained in the pores will crystallize and destroy them, by an action similar to that of frost.

70. Both zinc and copper salt must be of the very best quality, the salt free from iron, which is the principal impurity, and the zinc from lead.

Test for the purity of sulphate of copper.—To detect iron, dissolve the crystals in water, and add liquid ammonia; this will at first precipitate both the copper and the iron, making the solution appear cloudy; but if more ammonia is added the copper will be re-dissolved, forming a bright blue solution, while the iron will remain as a brown powder. Good sulphate should contain a mere trace of iron. The following is an analysis :—

Pure sulphate of copper	98·48 per cent.
Sulphate of iron	0·12 „
Extraneous water	1·40 „

Zinc.—Zinc contains carbon, lead, and iron; the latter is partly derived from the melting-pots, which should be lined with fire-clay. Four parcels submitted to analysis contained respectively:—

Zinc .	99·27 .	98·76 .	97·85 .	98·85 per cent.
Lead .	0·67 .	1·18 .	2·05 .	1·13 „
Iron .	0·06 .	0·06 .	0·10 .	0·02 „

The purest sample was Silesian spelter.

71. In order to ascertain the working condition of a battery, it should be tested with a detector wound with two or three yards of thick wire ("Quantity detector"), or with an ordinary detector, whose sensitiveness is reduced by a "shunt" so as to allow but a very small portion of the current to flow through its coils. One cell in good order will give as large a deflection as 100 of the same kind, but if any one of the 100 is defective, the deflection will be less than that given by a single good cell; thus one bad cell will spoil the entire set.

The trough which is faulty should first be found, and then the particular cell of that trough; which may be cut out by connecting the plates with wire (45).

72. The following are the most usual faults of the Daniell:—

Weak current.—Sulphate of copper exhausted. Sulphate of zinc solution too strong, perhaps crystallized upon the zincs; it should never be allowed to become more than half saturated. Zincs covered with a deposit of copper. Terminals corroded, or encrusted with dry sulphates (this fault is very frequent). A cell partly empty, the liquid drawn off by the syphon-like action of the crystals of sulphate of zinc (46). Dirty connections; battery making earth from damp; wires badly insulated, making earth or contact. Filaments of deposited copper extending across from the copper to the zinc plate.

Intermittent current.—A battery plate broken, touching at times, and at other times becoming separated. Loose battery wire.

No current.—Broken battery wire or plate; empty cell; battery wires in contact, perhaps where stapled down to the table or wall; or wire in contact with earth.

It often happens that the copper plate is eaten away near the surface of the solution when the supply of sulphate of copper is exhausted.

PART II.

RESISTANCE AND THE LAWS OF THE CURRENT.

73. WHEN the poles of a battery are connected by a conductor, so as to form a *circuit*, the electricity is assumed to flow as a *current* from the zinc to the copper plate through the battery itself; and from the positive or copper to the negative or zinc pole, through the conductor (23).

A telegraph *circuit* consists of the battery, the instruments, and a conductor composed of the line wire and the earth. A return wire is used instead of the earth when the circuit is very short.

74. Owing to the rapidity with which the electric force is propagated in the form of a current, when not influenced by induction, any effect which can be produced at hand can be produced at a distance at the same instant of time, subject to a diminution of force arising from causes which diminish the *quantity* of electricity or force of the current before its arrival at the distant end, and thus weaken the signal; for the strength of all telegraphic signals, including the deflection of the galvanometer, depends upon the *quantity* of electricity passing through the receiving apparatus in a given time. The causes of diminution of force are the *resistance* of the circuit and defective insulation.

If the tension of the battery is increased, it is with the view of overcoming the resistance of the circuit, so that more electricity

may pass in a *given time*. If two batteries be compared, it will be found that the strength of the signal through a large resistance is exactly proportional to the tension as shown by the electrometer.

75. The strength of the current depends upon two things: the *electromotive force*, or difference of *tension*, which sets the current in circulation; and the *resistance* the electricity has to surmount. Or (as stated by Ferguson) the *electromotive force* of the voltaic pair is proportional to the intensity of the chemical action; the *current strength* (quantity) to the amount of this action, or the quantity of zinc dissolved in a given time; and the *resistance* is that which prevents the former from generating the latter.

76. *Resistance* is the obstruction offered to the current by the bodies through which it is made to pass, and is the opposite, *reciprocal*, or converse of their conducting power or *conductivity*. When resistance is so great as to approach infinity, it becomes *insulation*.

All bodies do not conduct equally well; each has a certain *specific resistance*, that is, a resistance peculiar to itself.

Silver, for instance, has less resistance and higher conductivity than any other known substance.

If pure silver[1] be taken as having a conducting power of	100·0
Pure Copper (hard drawn) will be equal to	99·9
„ Gold (hard)	78·0
„ Zinc (pressed)	29·0
„ Platinum (soft)	18·0
„ Iron (soft) (nearly)	16·8

[1] According to Matthiessen's most recent determinations. The conducting power of the *metals of commerce* differs very widely from the figures given in the text. Impurities always lessen conductivity.

Pure Tin (soft)	12·3
„ Lead	8·3
„ Mercury (commercially pure)	1·6

Saline and acid solutions, though the best of liquid (non-metallic) conductors, offer enormously more resistance than metals, thus:—

If the resistance of copper be	1,
That of 1 part sulphuric acid to 11 of water will be	1 million,
That of a saturated solution of sulphate of zinc will be	16 millions,
That of a saturated solution of sulphate of zinc diluted with equal parts of water will be	14 millions,
That of a saturated solution of sulphate of copper will be	17 millions,
And of distilled water	6,754 millions.

77. If a constant battery be connected with a galvanometer by wires of various thicknesses and lengths, it will be found that the greater the resistance introduced into the circuit the less the needle is deviated, showing that the current is enfeebled. The relative resistances of different wires may thus be compared. If two wires introduced in turn into the circuit produce the same deflection, their resistances are equal.

78. Instead of comparing the resistance of one wire with another arbitrarily, it is convenient to fix on some one standard to which all may be compared. For instance, if one mile of No. 16 copper wire (the gauge ordinarily used for tunnels and underground work) be placed in circuit, and the deviation of the needle noted, we can find by trial how much copper wire or German silver wire (the resistance of which is greater than copper) must be used to produce the same deflection with the same battery and galvanometer. This wire, if wound on a

bobbin and preserved, becomes our mile measure. If a number of bobbins are filled with fine wire equal in resistance to various lengths of the No. 16 wire, we obtain a *rheostat*, or set of resistance coils, adapted to this standard.

79. Several standards or *units* of resistance have been proposed. The unit adopted by the electricians of this country is that determined by a Committee of the British Association, and is called the "*ohm*" (from Ohm, who first ascertained the laws of electrical resistance), and sometimes the "*B. A. unit*." It must be understood that the *unit* is a measure of *resistance*, in the same way as the yard, inch, or mile is the measure of *length*.

"Siemens' unit" is the resistance of one metre[1] of pure mercury, of one square millimetre section, at a temperature of 32°. The Siemens' unit being taken as 1,000, the ohm will be 956; in other words, the ohm is 4·4 per cent. smaller than the Siemens. The French unit is one kilometre of the iron wire in general use, four millimetres diameter, and its value is about nine ohms: the objection to this measure is that no two kilometres, even of the same wire, are exactly equal in resistance.

All experiments for resistance can be as well performed with an artificial line made up with resistance coils as on the actual telegraph, provided we do not require to take into account the effect of bad insulation.

80. The resistance of metals increases with temperature, while that of saline solutions decreases, so that during very accurate measurements the temperature must be kept constant and it is necessary to use for resistance coils a metal affected a little as possible by variations of heat.

Matthiessen states in the Report of the British Association Committee on Standards of Electrical Resistance, 1863, that pure iron varies between zero and 100° Centigrade (32° and

[1] The metre is equal to 39·37 inches; the millimetre, 0·039 inches.

212° Fahrenheit) as much as 39·2 per cent., other pure solid metals 29·3, while German silver varies only 4·4 per cent. (See Table 10.) It is therefore the best of the ordinary materials for the purpose. An alloy of silver with 33·4 per cent. of platinum, varies only 3·1 per cent.

81. The comparative purity of a metal affects its resistance most materially. In copper this is particularly marked—so much so, that the copper wire of No. 18 gauge now used conducts nearly as well as older wire of No. 16 gauge. Lake Superior copper, according to Matthiessen, has a conducting power of 92·6 per cent. (pure copper being 100), Burra Burra 83·7, Rio Tinto only 14·2 per cent. It is therefore necessary to test carefully the specific conducting power of all copper wire supplied for telegraphic purposes. It should not be less than 80 per cent., for wire of this quality can readily be obtained. For cables the average is over 90 per cent.

82. The resistance of a solid conductor, such as a telegraph wire, is in direct proportion to its length, and in the inverse proportion of its weight per mile. Ten miles of wire offer tenfold the resistance of a single mile of the same wire.

The resistance lessens as the size of the wire increases, in the ratio of the square of its diameter. It will take four wires an $\frac{1}{8}$ of an inch thick to make up the substance of a single wire $\frac{1}{4}$ of an inch thick, and the $\frac{1}{4}$-inch wire will offer only a quarter of the resistance of the $\frac{1}{8}$-inch wire, the lengths being equal. Four miles of the thick wire will conduct as readily as one mile of the thin. If the thickness of the wire be increased to $\frac{3}{8}$-inch, nine miles will for the same reason offer the same resistance as one mile of the thin conducting wire (nine being the square of three).

Hence the advantage of a thick line wire. If the battery and instrument offer a comparatively feeble resistance, as good a signal can be produced at nine miles' distance with a wire $\frac{3}{8}$-inch diameter, as at one mile with a wire only $\frac{1}{8}$ thick. A further

advantage is that a thick wire need not be insulated so carefully as a thinner one.

The resistance of the iron wire most generally used is—

[1] No. 4	. . .	7·8 ohms per mile.
„ 8	. . .	13·5 „
„ 11	. . .	23·0 „

"Homogeneous" metal and steel have a higher resistance.

83. The battery itself forms part of the circuit, and its resistance is a matter of great importance. This resistance consists of that of the liquids with which it is charged, and of the porous division which separates them. It is modified by the size of the plates, for the larger the plates the greater the area of the liquid, and the less its resistance; and by their distance from each other, for the closer they are placed the shorter is the liquid conductor. As liquids are bad conductors (76), the size and distance of the plates have a very great influence on the resistance of the cell.

The material of the porous division is generally a non-conductor, so that the current passes entirely by its pores. The introduction of porous divisions therefore increases the resistance of the cell, by decreasing the area of the liquid.

84. As a battery is merely a number of cells connected in series, its resistance increases in direct proportion to the number of cells composing it.

The electromotive force also increases in the same proportion. Ten cells will have tenfold the force of one cell (25), and ten times the resistance.

85. Every part of a circuit (including, of course, the battery), whatever be its form, nature, or resistance, is traversed in a given time by equal *quantities* of electricity; just as in a river

[1] This must be considered merely an approximation; a very slight difference in the gauge or in the temperature will cause a great variation in the resistance. A careful test recently gave 14·28 ohms per mile for No. 8.

the same quantity of water passes any given part of the channel each minute, whether the stream be narrow or broad, shallow or deep; because each part is supplied by that which precedes it, and in the like manner supplies the succeeding length. But the *tension* will *decrease* regularly at equal intervals of *resistance*, from a maximum at the end nearest the battery, to zero at the distant end where the wire is connected to earth (25).

86. The current through the circuit will equal the electromotive force of the battery, divided by the sum of the resistances of the battery, conducting wire, and apparatus for signalling, forming the circuit.

Call the electromotive force . . . . . E
„ battery resistance . . . . . R
„ apparatus and line resistance . . L
„ and the quantity of the current. C

$$\text{Then } C = \frac{E}{R + L}.$$

This is one of Ohm's celebrated laws, and is the basis of all the mathematical laws of electric currents.

It is evident that the less the resistance (R + L), the more current (C) will pass in a given time; or, in other words, the greater will be its quantity.

87. Take a battery of 24 cells, whose resistance (R) is 120 ohms, and whose electromotive force (E) is 10 per cell, or 240 for the 24 cells.

A. Connect it to a "*quantity*" detector (59), whose resistance, L, is so small that it may be neglected. The effective strength or quantity of the current will, in this case, be $\frac{E}{R} = \frac{240}{120} = 2$

Take off half the battery . . . . . $\frac{\frac{1}{2}E}{\frac{1}{2}R} = \frac{120}{60} = 2$

Remove all but a single cell . . . . . $\frac{\frac{1}{24}E}{\frac{1}{24}R} = \frac{10}{5} = 2$

Thus, when there is an infinitely small *external resistance*, or when the conductor connecting the poles of the battery is so large that it offers no appreciable obstacle to the current, one cell will give as large a deflection as any number that may be connected in circuit. For *each cell brings its own resistance with it*, and the increased electromotive force is solely occupied in overcoming this increased resistance. If, then, the *resistance* of a circuit be increased in the same proportion as the number of cells in the series, the deflection will remain unaltered.

This is expressed generally thus—If, under such conditions, we have n cells (n representing the number of cells in the battery), $\frac{n\,E}{n\,R}$ will equal $\frac{E}{R}$.

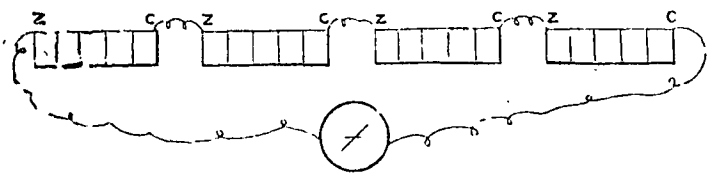
B. But if the same battery be tested with a detector wound with fine wire, whose resistance (L) is 120 ohms—

With 24 cells	$\frac{E}{R+L}$	=	$\frac{240}{120+120}$	= 1·0
With 12 cells	$\frac{\frac{1}{2}E}{\frac{1}{2}R+L}$	=	$\frac{120}{60+120}$	= ·6
With 6 cells	$\frac{\frac{1}{4}E}{\frac{1}{4}R+L}$	=	$\frac{60}{30+120}$	= ·4

Here the deflection increases with the number of cells, but not exactly in proportion to the number added, for *each cell brings its resistance with it, and thus lengthens the circuit.*

88. Connect the same battery to a wire, the resistance of which, including the galvanometer, is but 20 ohms.

BATTERY RESISTANCE (R) = 120 OHMS.



LINE AND GALVANOMETER (L) = 20 OHMS.

FIG. 4.

The quantity of the current, as measured by the deflection of the galvanometer, will be $\frac{240}{120 + 20} = 1{\cdot}7$.

89. "Double the quantity," as it is technically termed, by placing two similar sets side by side, connecting the two terminal zincs together, and the two terminal coppers, thus:—

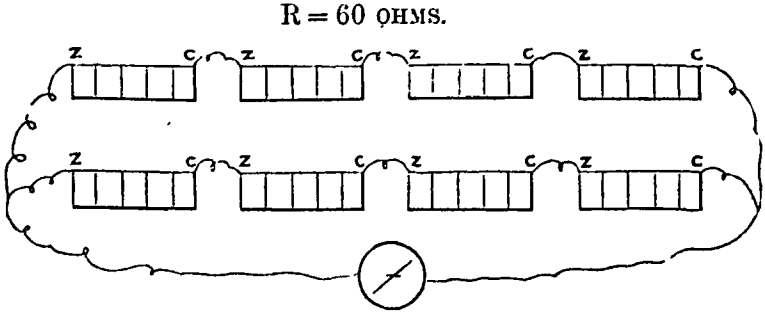


FIG. 5.

The electromotive force of the battery will be the same as with the single set, while its resistance will be halved, because the size of the plates is doubled.

Therefore the quantity will be $\frac{240}{60 + 20} = 3{\cdot}0$, or nearly double.

90. Connect the two sets in series for tension, thus:—

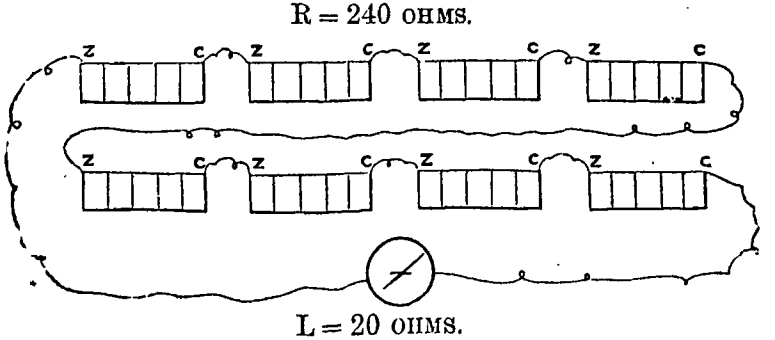


FIG. 6.

The electromotive force will be doubled, but the battery resistance will also be doubled, and

the quantity will be $\frac{480}{240 + 20} = 1{\cdot}9$ nearly.

or only ·2 greater than with half the number of cells, for the extra number of cells are almost entirely employed in overcoming the resistance they have brought with them.

91. Connect the battery to a wire and galvanometer, whose resistance (L) is 1,000 ohms.

With 24 cells the quantity will be $\frac{240}{120 + 1000} = {\cdot}21$.

With two series of 24 cells, arranged for "quantity," $\frac{240}{60 + 1000} = {\cdot}22$, nearly the same as with one series. And with two series arranged for tension $\frac{480}{240 + 1000} = {\cdot}39$ nearly, or almost double the effect of half the number of cells.

92. Thus, the *greater* the resistance of the *line*, the *less*, proportionately, is the effect of the resistance of the *battery;* and the *less* the resistance of the *line*, the *greater* the effect of the resistance of the *battery.*

93. On a short line, or a badly insulated long line, the size of the plates may be increased with advantage, for, the resistance being less, the battery "works the harder," and is sooner exhausted.

On a long circuit there is little or no advantage in increasing the size of the plates *if the line be well insulated,* but great advantage, up to a certain limit, in increasing their number.

94. It sometimes happens that a supply of large cells, or "quantity" batteries, is not at hand for a faulty line, or a local circuit. The following calculation will show how to produce the greatest possible effect with a given number of equal small batteries for a temporary purpose :—

Suppose the line has a resistance of 80 ohms:

The number of cells 120, in 12 troughs of 10 cells:
The resistance of each trough 60 ohms:
The electromotive force of each trough 100, as before.
(i.) If connected in single series—

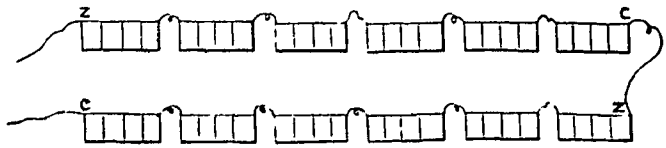


FIG. 7.

The electromotive force will be . . $12 \times 100 = 1200 = E.$
The resistance of the batteries . . $12 \times 60 = 720 = R.$
The resistance of the line . . . . . $80 = L.$

$\frac{E}{R+L}$, or the electromotive force divided by the total resistance, gives $\frac{1200}{800} = 1{\cdot}5.$

(ii.) If connected in two series of 6 troughs each—

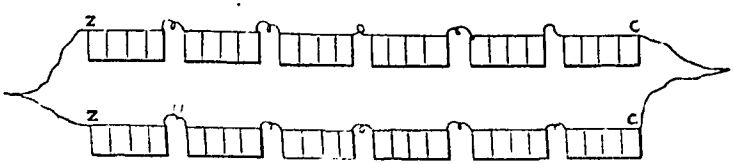


FIG. 8.

The electromotive force will be $6 + 100 = 600$
The resistance of the batteries $\frac{720}{2+2} = 180$[1]
The resistance of the line 80
And the current in circuit. . . $\frac{600}{260} = 2{\cdot}3$

[1] The resistance of the battery is reduced to one-half, because there are but half the number of cells. This resistance is again halved, because each cell is doubled in size. Hence the resistance of the doubled series is 2×2 = one-quarter of the original resistance.

(iii.) If connected in 3 sets of 4 troughs—

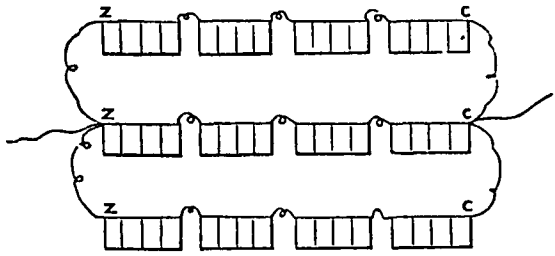


FIG. 9.

Electromotive force . . . $4 \times 100 = 400$

Resistance of batteries . . $\frac{720}{3 \times 3} = 80$

Resistance of line 80

The current in circuit . . . $\frac{400}{160} = 2{\cdot}5$

(iv.) If connected in 4 sets of 3 troughs—

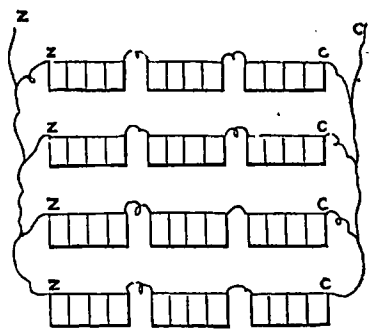


FIG. 10.

Electromotive force . . . $3 \times 100 = 300$

Resistance of batteries . . $\frac{720}{4 \times 4} = 45$

Resistance of line 80

The current in circuit . $\frac{300}{125} = 2{\cdot}4$

The greatest effect, then, of a given number of cells is produced when they are so arranged that the battery resistance

equals that of the line, as in No. iii.; and consequently, when a battery is placed on that line which is best adapted to it, the current it will give is exactly one-half of that which it gives when on short circuit, or when the resistance of the *line* is nothing.

95. Theoretically, then, the maximum effect of a certain given surface of zinc is attained when it is divided into so many plates that the resistance of the battery shall equal that of the line. It has been argued from this, that the plates ordinarily used may be reduced in size with economy.

For a single experiment, such as testing a tunnel, a battery of small plates constructed on this principle is useful; not so for continued use on a circuit. For in practice the resistance of a line of telegraph constantly varies. The battery, if calculated for a perfect state of insulation, will not only theoretically but practically have too much resistance when a fault occurs on the line, or when rain comes on. Besides this, causes which affect the constancy of a battery, such as the fouling of the plates, polarization, &c. &c., have a greater effect on the small pairs, because they are spread over a small surface, while, if the plates were doubled in size, the deposit or the gas would have double the space to cover, and would do less harm.

96. The cells should be so large that the battery shall offer considerably less resistance than the line. It should have sufficient electromotive force to overcome the resistance of the line, and be able to supply sufficient electricity to make up for the losses on the way.

97. There is a disadvantage in making up a "quantity battery" by connecting batteries of small plates side by side. Unless they are perfectly equal in power and conductibility, the stronger will have a tendency to send a current back through the weaker; for a battery must not be considered merely as a producer, but also as a conductor of a current.

When Daniell's batteries are thus associated for "quantity" for a considerable time, one must, sooner or later, overpower the

other; when this occurs the sulphate of copper of the weaker battery is driven through the porous cells, and copper is deposited on the zinc, annihilating the electromotive force and producing great local action. Hence it is much better to use one plate of 32 square inches, than two of 16 square inches placed side by side.

THE EARTH.

98. It was at one time imagined that the earth completed the circuit precisely in the same manner as a return wire; this opinion is now considered incorrect. Gavarret[1] explains the actions thus:

"The poles of a battery, when disconnected, have equal and contrary tensions.

"When insulated conductors are placed in contact with them, they themselves become the poles of the battery, the battery having furnished a current sufficient to charge them, but not of *sufficient duration* to move a galvanometer needle.

"If the conductors are enlarged, the time occupied in charging them will increase, until, as they are still further enlarged, a limit will be reached at which the flow of electricity into them *will last long enough* to affect the galvanometer; and when the conductors become infinitely long or infinitely large, the time occupied in charging them also becomes infinite, or, in other words, the current will pass precisely as if the poles were connected.

"Thus, when the extremities of a circuit are connected to the earth, which is an infinitely large conductor, their respective tensions are diffused in all directions without producing any

1 "Télégraphie Électrique," par A. Gavarret, p. 35.

appreciable alteration of tension in the earth itself, so that the current will continue to flow.

"The earth acts as an ordinary conductor, and opposes some resistance to this diffusion."

Another view is, that as whenever one kind of electricity is produced, an equal quantity of the opposite is also produced; and as both electricities are ultimately transferred to the earth, they neutralize one another, because of the earth's perfect conductibility.

When a layer of soil placed in a box is compared with a similar layer forming part of the earth's surface, it is found that the isolated portion offers the greater resistance. Its resistance follows the same law as that of any other substance, depending on its dryness or dampness, its nature, and its length and section.

If two earth plates be buried in the soil, the resistance of the portion included between them does not vary in the ratio of their distance, as it would if the portions were enclosed in a box. Blavier[1] gives the following results, which were obtained by Matteuci: the size of the plates being the same in each case:—

			Resistance.		Resistance.
Plates	1	yard apart on the level plain,	68,	on a mountain,	152
„	5	„ „	97	„	—
„	10	„ „	102	„	222
„	20	„ „	109	„	—
„	50	„ „	120	„	531
„	100	„ „	—	„	849

The resistance diminishes inversely as the depth to which the plates are buried.

When buried	4	inches	the resistance was	91.
„	10	„	„	83.
„	40	„	„	74.
„	80	„	„	70.

[1] "Télégraphie Électrique," par E. E. Blavier.

The size of the plates has the greatest influence on the resistance.

If a plate containing 1 square foot of surface gives a resistance of 174,

A plate of 4 square feet will give a resistance of 140.
" 16 " " " 81.
" 25 " " " 47.
" 32 " " " 31.

But after a certain *size*, varying with the conducting power of the soil around the plates, the resistance remains constant. In the sea this limit is very quickly reached.

After a certain *distance*, varying with the conducting power of the soil and the size and depth of the plates, a further increase of distance makes no difference in the resistance.

This diffusion or conduction does not take place solely in the direct line between the two plates, but extends in curved lines on all sides. It is thus easily seen why the resistance decreases with the depth to which the plates are buried, is less on a plain than on a mountain, and is greater when a portion of soil is isolated by being placed in a box, for then conduction takes place only in the direct line, and there can be no diffusion.

On short lines the resistance of the earth to the diffusion of the current is a matter of the greatest importance.

If the earth terminals of the several circuits or wires are connected to one and the same earth plate, it becomes a question of comparative resistances whether a current sent on one wire shall diffuse itself through the earth, or shall divide between the earth and the other wires. The earth-plates should in this case be large, and be buried deep in soil wet at all seasons.

It sometimes happens that an "earth cannot be found," in places where there is but a thin layer of soil covering rock, or where the soil is constantly dry.

Instead of connecting all the wires to the same earth-plate,

use separate plates buried fifty yards or more apart, so that the resistance of the soil between the plates may be greater than the resistance of the earth to the diffusion of the tensions.

When this plan cannot be carried out, the resistance of the shorter circuits may be increased by resistance coils, in order to lessen the tendency to leakage from the circuit of greater resistance to that of lesser resistance.

To test an earth-plate, send a current on one wire, and place a sensitive galvanometer on the shortest of the others; one fixed on separate poles, if there is more than one line. If no current passes through the galvanometer, the earth is perfect.

A water or gas pipe is preferable to a plate, because of its larger surface. Care must be taken to connect the earth wire to the main street gas-pipe, as the joints indoors are frequently packed with white lead, and leaden gas-pipes have been fused by lightning by sparks passing between them and adjacent conductors. It is best to use both water and gas pipes, so that, if one be under repair, the other shall complete the circuit: a well-soldered connection should always be made.

A deep narrow trench filled with coke, in which a copper plate, or what is better, a strip of lead, is buried, may sometimes be used, bearing in mind that the object is to expose as large a surface as possible.

Plates must always be buried *flat*, and not coiled into a cylinder or spiral, and upright rather than horizontal.

On connecting up a circuit of less than ten miles, it frequently happens that a permanent current appears on the instrument, arising from the earth-plates forming a battery. If an iron gas-pipe be used for an earth at one end, and a lead water-pipe or a buried plate of copper at the other, a current is always set up.

It is necessary, then, to be careful that both earths are as nearly as possible alike, and to change one or both till the current ceases.

PART III.

MAGNETISM AND ELECTRO-MAGNETISM.

99. PIECES of iron or steel which have long remained in a north and south position, or have been subjected to certain mechanical and electrical processes, attain the power of attraction and repulsion, and are called *magnets.* Some of the ores of iron possess the same property, and are called *natural magnets* or *loadstones.*

100. If a magnet be balanced on a pivot so as to be free to move horizontally, as in the mariner's compass, it will place itself in the *magnetic meridian;* that is, point *north and south.* The end which points to the north is called the *north pole;* that which points to the south, the *south pole.*

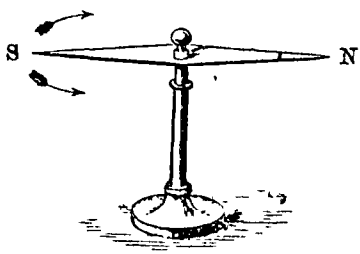


FIG. 11.

If a steel bar be balanced on a horizontal axis so that it may move freely in a vertical plane, it will remain at rest in any position. Magnetize it, and the north end will appear to have become heavier, or will *dip,* unless it be placed east and west, when the magnetic force will simply produce pressure on the pivot; for the manner in which it is pivoted prevents it moving when in this position.

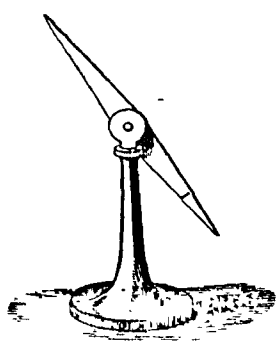


FIG. 12.

The north pole is generally marked either by the letter N, or by a file-cut, as in the figure, and is sometimes called the *marked*, while the other is called the *unmarked* pole of the magnet. It is also sometimes called the *negative*, the other being called the *positive* pole, and they are designated, as in electricity, by the signs – and +. There is no difficulty in recollecting which is which, because the N or – sign stands equally for negative or north.

101. When two magnets are brought near one another, the similar poles will be found to repel, the dissimilar poles to attract. That is, the north pole of one will repel the north pole and attract the south pole of the other, and *vice versâ*. But if a piece of iron or *unmagnetized* steel bar be used, either pole will be attracted, and no repulsion whatever will occur.

Bodies attracted by a magnet, themselves attract the magnet with equal force.

MAGNETIC INDUCTION.

102. Magnetism acts by *induction* at a distance through all substances not themselves capable of being magnetized. A compass in a brass or wood box is as easily affected as if it were not so enclosed; but if shut in an iron box, a magnet outside would act on it indirectly only and feebly, through the magnetism induced in the iron of which the box is composed.

The immediate neighbourhood of a magnet is called the *magnetic field*, and pieces of iron or steel, magnetized or unmagnetized, brought into this field, acquire magnetic power by induction. Hence, if a small or weak magnet is used to test the polarity of a stronger one, it is necessary to keep it at a distance; for when brought too near, the superior power of the stronger

overpowers the polarity of the weaker for the time being, and attracts either pole indifferently. Hence if it be desired to find whether a pole be N or S, ascertain by which pole it will be *repelled.*

The attraction of two dissimilar poles is greater than the repulsion of two similar ones. In attraction, each tends to develop in the other a magnetism opposite to its own, and similar to that of the other, and thus strengthen each other. In repulsion the opposite effect takes place.

The magnet acts upon iron by inducing an opposite polarity in the part nearest to itself, and in consequence the two dissimilar poles attract each other, so that the iron will adhere to the magnet when placed in contact with it. The opposite extremity of the piece of iron exhibits the same polarity as that of the magnet itself, and will attract a second piece of iron (Fig. 13).

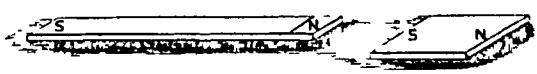


FIG. 13.

Nearly all traces of magnetism in the iron cease as soon as it is removed from the influence or *field* of the magnet, for *iron* cannot retain magnetism, or cannot be permanently magnetized, when soft and pure. When hard or impure, it retains a certain amount of polarity, which is called *residual magnetism.*

Steel, on the other hand, is not attracted as forcibly as iron; it acquires magnetism with greater difficulty, but retains it more or less permanently. The harder the steel, and the longer the bar, the more permanently will it retain its magnetism.

103. The inductive force of a magnet upon soft iron varies inversely as the distance between them, while the action of one magnet upon another varies as the square of the distance, so long as they are so placed that the two adjoining poles act upon each other free from the interference of the remaining poles.

104. If a magnetic bar be tested, it will be found that its force appears to reside very near the ends or *poles*, and that it decreases to nothing at the centre of the length of the bar. If a magnet be broken into any number of pieces, each piece will become a perfect magnet; but if the pieces are placed closely together again, the intermediate poles will disappear, and the magnet will have only two poles, as at first. The magnetism, however, is really distributed throughout its mass.

105. A straight bar is called a bar magnet; the small bar magnets used in telegraph instruments and ships' compasses are called *needles;* and when a bar is bent, so as to bring its two ends or *poles* near one another, it is called a *horse-shoe* magnet.

A *compound* magnet consists of two or more bar or horse-shoe magnets placed side by side, with their similar poles in contact. Care must be taken that all the bars are equal in power, or the feebler will be weakened, or even reversed, by the stronger.

The advantage of forming a magnet of several thin bars instead of a single thick one is, that the thinner bars are more easily magnetized. But if two bars equal in power be placed together, the combination will not have double the strength of the single bar, but only about half as much again. This is because of the reaction of the similar poles upon one another.

106. The processes for magnetizing steel bars, or forming artificial magnets, are founded on the principle that a north pole induces a south pole, and *vice versâ*.

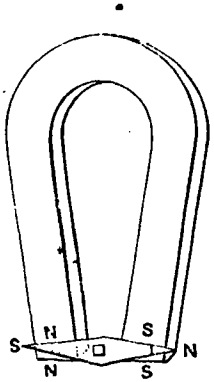


FIG. 14.

A magnet can only be charged to a certain maximum, called the *point of saturation*, and this point is generally ascertained by the weight which the magnet is capable of bearing. The small magnets employed in needle telegraphs should be capable of bearing their own weight together with that of the axle.

To magnetize a small bar such as the *needle* of a telegraph instrument, all that is necessary is to lay it across the poles of a horse-shoe magnet, the end required to be the north pole on the south pole of the horse-shoe, and *vice versâ* (Fig. 14); rubbing them together once or twice in the direction of the needle's length.

To magnetize a pair of bars of several inches in length, place them flat on a table, as in Fig. 15, between two pieces of soft

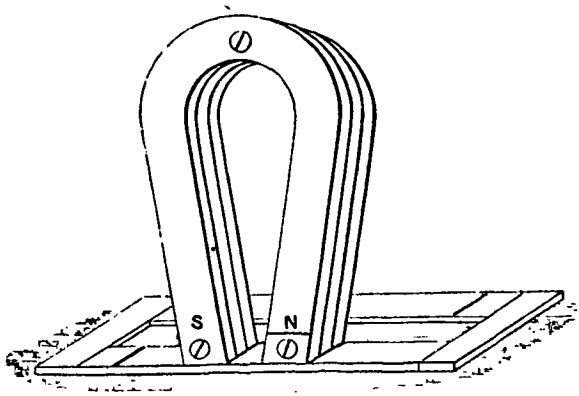


Fig. 15.

iron, as armatures. Place the horse-shoe magnet S N on one end of either of the bars, with its *north* pole upon that extremity of the bar which is required to become a *south* pole. Slide the horse-shoe along the bar, carrying it round the whole system several times, stopping finally in the centre of one of the bars, as shown in the figure. Repeat the process on the other face of the bars.

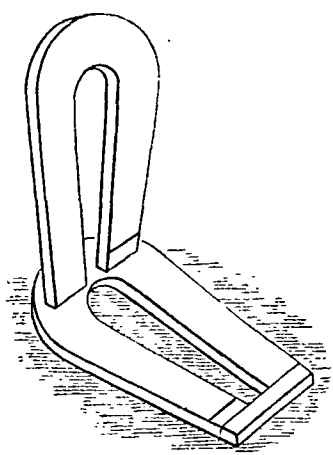


Fig. 16.

A horse-shoe may be magnetized in a similar manner, commencing at one end of the poles, sliding the magnet round the horse-shoe and its

armature, finally stopping at the centre of the curve of the horse-shoe (Fig. 16).

When a bar is carelessly magnetized, it may acquire one pole or more in addition to those at its ends, and will be found not to act as strongly as it should do.

107. If the north pole of a weak magnet be applied to the north pole of a stronger magnet, the polarity of the weaker magnet will first be destroyed (the bar will be *demagnetized*) and then *reversed*, the north becoming a south pole.

The earth itself is an enormous magnet, and objects upon its surface are constantly in its *field*, and subject to its influence; consequently, if magnetized bars are laid aside without regard to the direction in which their poles are placed, they become *demagnetized* by its action.

To prevent this loss of power *armatures* or *keepers* of soft iron are used, applied to or placed across the poles. When out of

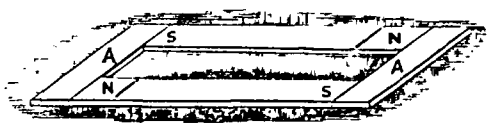


FIG. 17.

use, bar magnets should be placed as in Fig. 17, where A A are the armatures, and S N N S the magnets. The armatures become magnetized by induction, and in their turn induce magnetism in the bars. This mutual induction is more powerful than the inductive influence of the earth.

When several pieces of iron are hung from one of the poles of a permanent magnet, each one develops magnetism in the piece next to it, and its own magnetism is increased thereby. Hence the lifting power of a magnet may be increased by hanging to it, from time to time, additional pieces of iron.

108. The armature of a horse-shoe magnet will support a greater weight than would be carried by the two poles, because

of the mutual inductive reaction between a magnet and its armature.

The armatures of horse-shoe magnets are applied as in Fig. 18. They may with advantage be weighted, and if the weight is gradually increased, taking care never to make it sufficient to tear the keeper away (which would weaken the magnet), the strength of the magnet will be increased also.

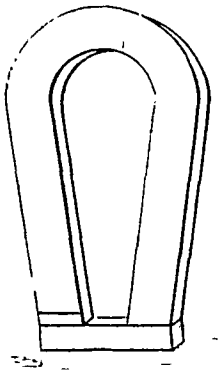


FIG. 18.

The armature should always be slid off, never forcibly detached.

The poles which attract each other tend to preserve each other's magnetism; those which repel tend to destroy it.

109. Needles free to move horizontally, as compass needles, always take up the position most favourable for retaining their power. This may seem to contradict what has been before said (100), since the north pole of the needle turns towards the north pole of the earth. But the north pole of the needle has really an *opposite* magnetism to that of the north pole of the earth, and strictly should be called the *south* pole, as in French works.

110. Magnets required to be set in motion by a slight force, as in telegraphs, must necessarily be short. They therefore lose their power readily, and are easily demagnetized by lightning, or even reversed. There is an advantage in making the moveable parts of soft iron, and pivoting them upon large permanent fixed magnets, so that they may be magnetized by *induction* (102). Large magnets retain their power for a long time.

111. Cast steel is best suited for permanent magnets: it may be tempered by being heated to a cherry red in a tube to prevent burning, and immersed in water.

ELECTRO-MAGNETISM.

112. A wire through which a current is flowing possesses, for the time, properties similar in some respects to those of a magnet. It attracts iron filings, and attracts or repels other wires through which currents are flowing, but it has no effect upon light bodies which would not be attracted by the magnet.

113. Two parallel conducting wires will attract each other if the currents flow in the same direction in both, and repel if they flow in opposite directions (Fig. 19).

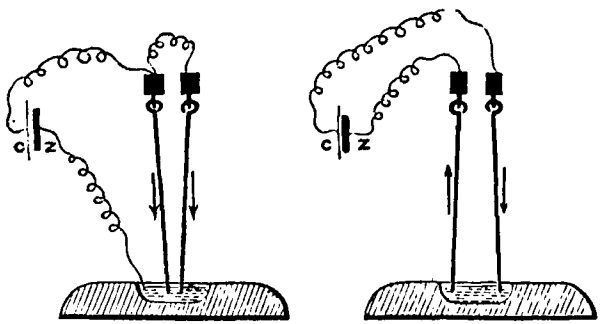


FIG. 19.

114. A conducting wire is in like manner attracted and repelled by a magnet, but in both cases the force is not simply one of attraction or repulsion, but one which would cause the wires, or the wire and magnet, to revolve round each other when so fixed or pivoted as to be able to move freely in all directions.

FIG. 20.

Let M be *one pole* of a magnet, and W a section or slice of a conducting wire; if W is fixed and M free to move in all directions, M will revolve round W (Fig. 20). But the *other pole* of the magnet M would tend to revolve in the *opposite* direction round the wire, so that in order to produce the *revolution* of a conducting wire around a magnet or of a magnet around a conducting

wire, they must be arranged so that the current acts upon one pole only of the magnet (Fig. 21).

115. If the magnet N S be fixed on an axis, as shown in Fig. 22, the tendency of its two poles to rotate in opposite directions round the current flowing in the wire will cause it to take up a position at right angles to the wire. For, as the two poles N S tend, when considered separately, to revolve round the wire in the direction shown by the arrows, the end N will be urged *towards* and S *from* the reader; but as the needle is pivoted upon a vertical point, it is capable of motion in the horizontal direction only.

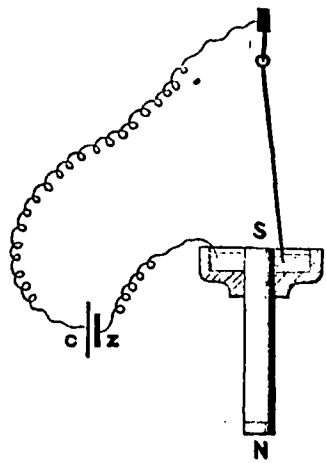


FIG. 21.

116. The following illustration, contrived by Ampère, is useful as an aid in determining in what direction a current will move a magnet.

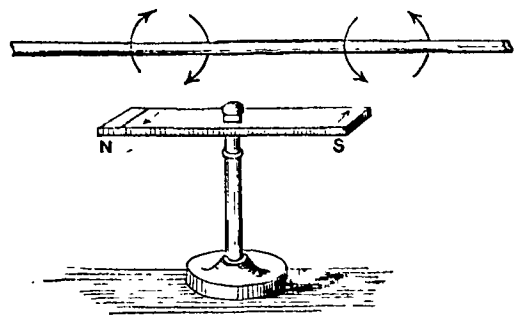


FIG. 22.

Suppose one's feet to be connected to the copper, and one's head to the zinc pole of a battery, the current would flow upwards through the body. If a magnetized needle suspended vertically, as in a needle instrument, be held before the breast, the north pole of that needle would be moved to the left hand, towards a position at right angles to the body. If the needle were held at the back, or if the direction of the current were reversed, the direction in which the needle would be moved would also be reversed.

In these diagrams the body of the person holding the needle is represented by the wire Z C, and the needle by S N.

The wire in front of the needle.

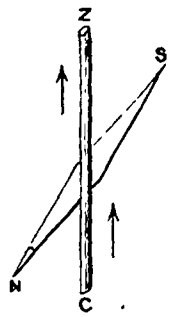


Fig. 23.

The wire in front of the needle, and the current reversed.

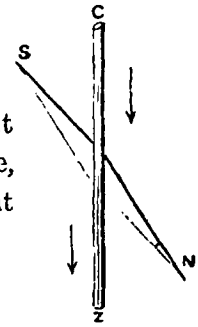


Fig. 24.

The wire behind the needle.

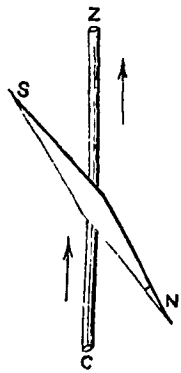


Fig. 25.

The wire behind the needle, and the current reversed.

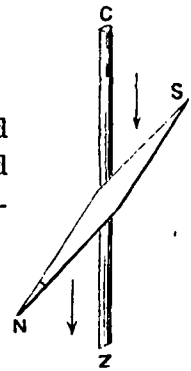


Fig. 26.

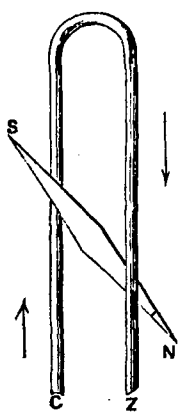


Fig. 27.

It will be perceived, that when the wire is bent round the needle thus (Fig. 27), its two halves act similarly on the needle, and the effect is doubled. The current ascends *behind* the needle, as in Fig. 25, and descends *in front* of it, as in Fig. 24.

If the wire be bent a second time in the same direction round the needle, the effect will be again doubled, and by a still further increase in the number of turns a corresponding increase in force will be obtained.

117. If the wire is covered with an insulator,

as silk or cotton, so as to compel the current to traverse its entire length, and is formed into a circular coil, or wound upon a frame, it may be so arranged as to make several hundred or even thousand turns around a magnet pivoted within it, and will move even with a very feeble current. This arrangement is called a *galvanometer*, or current measurer (120). The angle or number of degrees through which the magnet or *needle* is moved shows the *quantity* of electricity passing through the coils. The *direction* in which the needle is moved shows the *direction* in which the current is flowing.

118. A conducting wire, if straight, possesses no *polarity*, and its force is distributed equally throughout its entire length; but when bent to form a loop or ring, so that the parts which cross one another do not touch (Fig. 28), if one pole of a magnet be

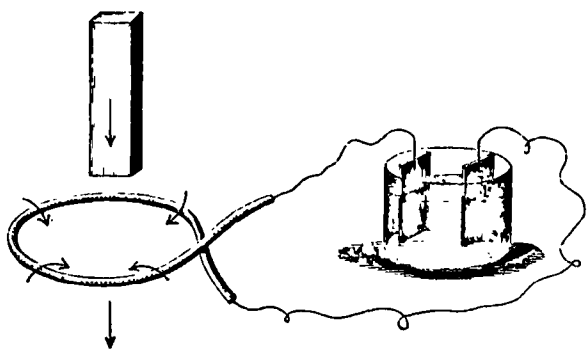


FIG. 28.

presented to the centre of the ring, the tendency to rotate will cause the magnet to be drawn into or expelled from the ring, according to the direction of the force of rotation. It will therefore appear to be attracted or repelled by the magnet. If properly suspended, the ring will be found to possess polarity, and will place itself north and south, the *edges* of the ring standing east and west. The effect is multiplied if the ring be formed of a number of turns.

119. If the wire be formed into a *helix* or spiral, its polarity will be more decided, and it will behave precisely like a magnet.

If the spiral be wound so that the current flows from *right*

FIG. 29.

to *left* (Fig. 29), that end of the wire which is connected to the + or copper pole of the battery will be a north pole. If, on the contrary, it be wound like an ordinary screw, so that the

FIG. 30.

current flows from *left* to *right* (Fig. 30), the + end of the wire will be a south pole.

The directive force of a helix is very clearly apparent in the apparatus shown in Fig. 31.

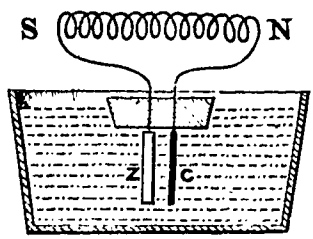


FIG. 31.

The conducting wire coiled as a spiral is connected to a voltaic pair, and arranged by means of a cork so as to float in a vessel of acidulated water.

120. There are two classes of galvanometers: one called a "*detector*," in which the needle hangs vertically, and is kept in place by the weight of its lower end (Fig. 32), and one in which the needle is poised on a point like that of a mariner's compass (Fig. 33). The latter form is much more sensitive than the former, because the friction of the pivot is less, and because it is not necessary to weight the needle, which is kept in its position by the directive action of the earth only; that is, by its tendency to stand north and

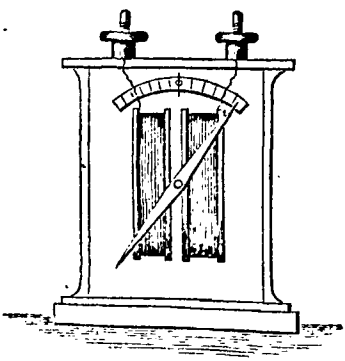


FIG. 32.

south. In using the horizontal galvanometer it must be carefully levelled; and as the needle will point to the north, the case must be turned so as to bring the coils into their proper position, and the needle to the zero of the scale. An ordinary detector may be used horizontally, that is, may be laid on its back, when it will be much more sensitive than when upright.

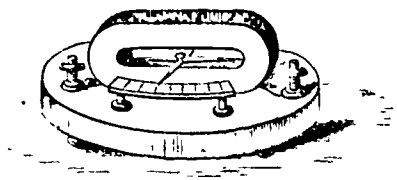


FIG. 33.

The use of a horizontal needle would be very tedious, were it not easy to check its swinging by making and breaking contact in such a manner that the current may oppose instead of aiding it. The application of a feeble magnet, such as a penknife, will produce the same result.

The vertical galvanometer needs no adjustment, the north end of the inner needle being made sufficiently heavy to keep it upright. Its sensitiveness may be considerably increased by lessening the weight of the lower or north end of the inner needle; but in this case the instrument must be so placed that its dial faces the north or south, or the *dip* (100) will cause the needle to hang on one side. Whenever the needle, of a needle instrument, which is simply a vertical galvanometer with a reversing key, will not hang vertically except the case is in one particular position, it is because of the dip. Needles properly balanced for this country will be found wrong if sent to Australia, for there the south end will dip, or appear the heavier.

121. As the needle of a *vertical* galvanometer is kept in its place by gravity, or the weight of its lower end, which is always the same, and as the force with which a current acts upon it depends on its magnetism, which is constantly decreasing, its indications vary from time to time. But in a *horizontal* galvanometer, as the needle is kept in its place

solely by its tendency to point north and south, the feebler its magnetism the less resistance will it offer to being moved by the current, while, on the other hand, the current acts with less force on a feeble magnet. The two thus counteract one another, and the instrument is *constant.*

122. In neither of these instruments is the graduation into degrees, or equal parts, correct when the deflection exceeds 20°; for the further the needle moves from a position parallel to the wires of the coil, the more nearly does it approach a right angle, where the effect is null; so that the action of the current upon it becomes less and less powerful as the deviation or deflection increases.

In a well-made vertical detector the values of the degrees marked on the dial were found to be *nearly* correct to 30°, and

40°	were equal to	44	parts of electricity.
50°	„	65	„
55°	„	78	„
60°	„	93	„
65°	„	130	„

But the value of the ordinary degrees would not be alike for any two galvanometers; each must be graduated by actual trial, or by comparison with a standard instrument.

123. In the *sine* galvanometer this source of error is avoided. The instrument is placed north and south, and the coils are made moveable, so as to *follow the needle* as it is deflected, until the directive force of the needle is exactly balanced by the force of the current, and stands parallel with the wires, when it again points to the zero of the graduation. Thus the needle is constantly in the same position with respect to the wire of the coil, and the current always has the same amount of leverage upon it. The forces measured by this instrument are proportionate to the *sine* of the angle

through which the coil has been moved, not to the angle itself.

The sine of any number of degrees is that part of the diameter of a circle which is included between a line drawn from its centre to the zero point of the graduation G 0 (Fig. 34),

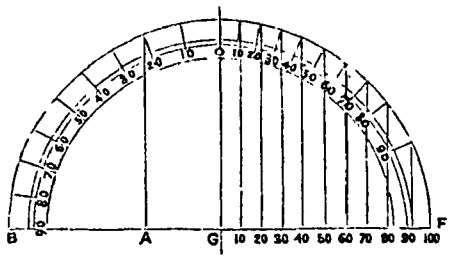


FIG. 34.

and another line parallel to the first, cutting the circle at the degree whose sine is required: thus A G is the sine of 20°, and G B is the sine of 90°. These sines evidently increase in a different ratio to the degrees they represent.

In using the sine galvanometer it is usual to read off the angle through which the coil is moved, in *degrees*, and to find the sine by a reference to tables given in mathematical works. For ordinary purposes, it is more convenient to graduate the instrument with a scale of sines, which may be constructed thus:

Divide the radius G F into 100 equal parts,[1] from which draw lines at right angles, and mark the points at which they cut the circle. The readings of a scale so formed will correspond with those which would be obtained if the deflection of the needle were read off in degrees, and reference made to the printed tables for the corresponding sines.

The diagram shows lines drawn at each tenth division.

124. A horizontal galvanometer may be greatly increased in

[1] The sine of 90° is equal to the radius of the circle, and in the tables is made equal to 1·00.

sensitiveness by making the outer needle or pointer a magnet; placing its poles in a contrary direction to those of the inner magnet (Fig. 35). If the two are exactly equal in power, the pair will have no tendency to point to the north, because the directive action of one will be counteracted by the equal and opposite action of the other, and the pair will be what is termed *astatic*. One needle should, in practice, be a little stronger than the other, so that the pair may have sufficient tendency to point north and south to enable it to regain its position after having been deflected. The more nearly the two needles are alike in power, which may be known by the slowness of their vibration, the greater the delicacy of the galvanometer.

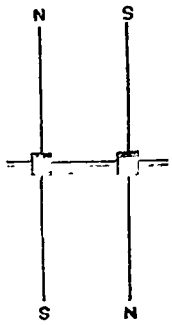


FIG. 35.

To obtain the greatest sensitiveness the needles should be exactly alike, and should be magnetized together; any excess of magnetism may then be removed from the stronger of the pair by the similar pole of a needle of equal strength. The nearer to the centre the touch is made, the more delicate will be the effect produced.

But an astatic galvanometer is not constant, for the *relative* force of magnetism in the two needles varies considerably from time to time.

125. By the use of a *directing magnet* the sensitiveness of a horizontal galvanometer may be varied to a great extent. The magnet should be of considerable power, and be placed upon a vertical rod passing through its centre, fixed above the coil immediately over the needle, in such a manner that it can be turned horizontally so as to follow the movements of the needle, or be removed nearer to or further from it, vertically.

If it is placed with its south pole over the north pole of the needle, it will add its directive force to that of the earth, and, by

holding the needle more powerfully in its position, will *lessen* its sensitiveness. The nearer the magnet is approached to the needle, the greater will be its power over it, and it can be arranged so as to hold the needle in any desired position.

But if it is placed in a reverse direction, so as to *repel* the needle instead of attracting it, it will lessen the directive force of the earth so as to increase its sensitiveness, and, in a certain position, will render the galvanometer astatic.

When the magnet is too near the needle, it repels it to the full extent of the scale; if it is raised upon the supporting rod, the repelling effect will decrease until at a certain distance of the magnet the needle can be held to zero.

The greatest sensibility is obtained at the point at which the slightest lowering of the magnet upon the rod will again repel the needle to the full extent of its swing.

126. The more nearly a needle, or pair of needles, is made to approach the astatic condition, the *slower will it vibrate;* and the *more powerfully* it is *directed,* or held in position, the *quicker will it vibrate.*

127. The *differential* galvanometer shows the *difference in strength of two currents.* It is wound with two wires side by side, so arranged as to be exactly equal in their effect on the needle. When, therefore, two equal currents are made to pass in opposite directions through the coils, they will exactly balance one another, and the needle will not move. If, however, one current be stronger than the other, the balance will be destroyed, and the needle will be moved by the stronger current, with a force equal to the difference in the strength of the two currents.

If the current from a battery be split or divided between two similar wires of unequal lengths, each connected to one of the coils, the greater part will pass through the shorter wire, overpower the effect of the weaker current in the other coil, and move the needle; if the shorter wire be now lengthened till it is

equal to the longer one, the currents will be equal in both coils, and the needle will again be immoveable.

In order to be able to balance widely differing resistances, one coil of the galvanometer is provided with *shunts*, say of 10, 100, and 1,000, which reduce the effect of the current upon it, so that the 100 ohms of a set of resistance coils connected with the shunted coil may be made to balance 1,000 or even 100,000 ohms' resistance connected with the other. (*See* APPENDIX.)

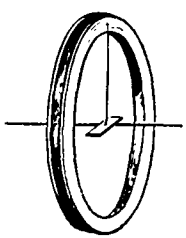


FIG. 36.

128. The *tangent* galvanometer consists of a ring having a groove on its edge filled with wire (Fig. 36). The needle is hung or pivoted precisely in the centre of the ring, and must not be longer than one-sixth of its diameter—an inch needle requiring at least a six-inch ring.

A *tangent* is a line drawn at right angles to one of the radii of a circle, and touching its circumference: A B and B D are tangents to the circle in Fig. 37.

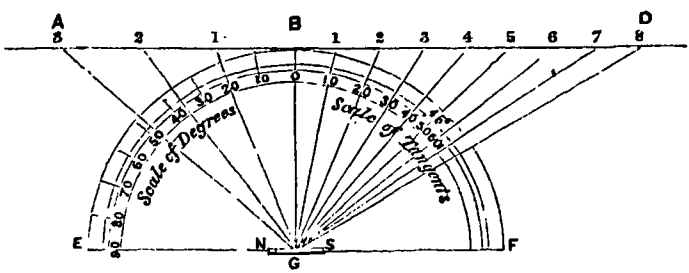


FIG. 37.

When a short needle N S, with a pointer attached to it at right angles, is suspended in the centre of a circular coil of wire fixed perpendicularly to the dial E B F, and the apparatus is so placed that the coil shall exactly face east and west, if the needle is deflected by a given current to 20 degrees, double the force will not deflect it a *second* 20 *degrees*, but to *double the distance measured on the tangent* A B. Thus, the equal divisions 1, 2, 3,

on the line A B, represent equal forces; and if the pointer be long enough to reach A B, these divisions will serve as a scale.

As it would be inconvenient to read off from the straight line, the circle may be divided with sufficient accuracy for most purposes, by drawing lines from the centre to each division on the line of tangents, marking where they cut the circle, as is shown at B D and B F. The greater the number of equal parts into which the straight line is divided, the more accurate will the divisions of the circle be; for these last divisions are not all the same length, but decrease as the angle of deflection increases.

In mathematical tables the tangent of 45° is 1·00, so that if this tangent of 45° be divided into 100 equal parts, and these set off on the circle, the readings will correspond with those which would be obtained were the circle divided into *degrees*, and the table referred to for the corresponding tangents.

Although from the distance between the coil and needle this instrument is not so sensitive as others, it is extremely useful for testing overground wires, because of the length of its scale and its accuracy. The wire should be comparatively thick, so that, with a given resistance, a large number of convolutions may be obtained; for the coil is so far from the needle, that the slight weakening of effect consequent on the increase of distance caused by the extra thickness of the wire, is far more than compensated by the increase of power arising from the additional number of turns.

A convenient form of tangent galvanometer is an inch needle, and a six-inch coil wound with number 24 or 30 wire having a resistance of about 50 ohms; the needle to be pivoted as in the mariner's compass.

129. An inch is a convenient length for the needle of all horizontal galvanometers. For ordinary use it may be pivoted as in a compass, and be placed inside the coil as shown in Fig. 33. The coil should be wound with number 35 silk-covered

wire to about 100 ohms' resistance. For testing insulated or covered wire, it may have a resistance of 2,000 ohms, or about 3,000 turns of number 40 wire. Very delicate galvanometers are constructed with more than 30,000 turns, with astatic needles, the coils being double, as in an ordinary detector, to allow the axis of the pair of needles to be placed between them. The needles are suspended upon a fine unspun silk thread.

When delicate galvanometers are disturbed by masses of iron, such as locomotives, moving in their neighbourhood, they may be enclosed in a sheet-iron case (102).

A galvanometer with few turns is best adapted for testing short lengths or small resistances: the longer the length and the greater the resistance, the greater must be the number of turns.

130. *Electro-magnets.*—It has been shown (112) that a wire spiral conveying a current has for the time the properties of a magnet. When such a spiral is wound on a bar of soft iron, the iron becomes magnetized for the time by its action, and its force is added to that of the coil. Thus, the force of the coil and iron together is very much greater than that of the coil without the iron. This is called an *electro-magnet*, and its polarity depends upon the direction in which its coil is wound, as is shown in Figs. 29 and 30.

The electro-magnet has all the properties of a permanent magnet (a magnet made of tempered steel), so long as the current continues to flow: and it can be so constructed as to possess much greater power than it is possible to give to a permanent magnet.

If the iron be very soft and pure, it loses its magnetism immediately the current ceases; but if impure, or if hardened by hammering or turning, it retains a certain amount of *residuary* magnetism, especially when it has been acted on by a powerful current, or if the armature has been allowed to touch

the core. To prevent this, when the iron core for the electro-magnet has been formed, it should be made red-hot, and very carefully annealed by the fire being allowed to die out.

131. Electro-magnets are generally made in the horse-shoe form: that is, two bobbins are formed by fixing ivory or brass ends upon cores of the purest and softest iron; these bobbins are filled with covered wire and fixed upon a connecting bar of iron. They are fitted with *armatures* of soft iron in the same manner as permanent magnets (Fig. 38).

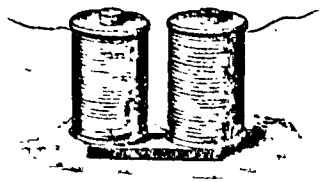


FIG. 38.

If the wire is wound upon a metallic bobbin into which the cores are made to slip, the bobbin must be slit from end to end, to prevent the circulation of the current induced in it by the magnetization of the iron; for this current would prevent its gaining or losing its power as quickly as it would otherwise do, and thus interfere with the rapidity of its action.

132. In electro-magnets, as in galvanometers, the effect of the current is multiplied by the number of the turns of wire in the coil.

It is lessened by an increase in the distance between the wire and the core, each turn acting less powerfully than the one beneath it. The wire should therefore be wound on the core itself.

The diminution of the effect of the current by increase of distance is not so great when the diameter of the coil is small compared with its length; so that a long electro-magnet is comparatively more effective than a short one.

The current itself is enfeebled by each addition to the length of the coil, because of its increased *resistance* (77); and this will be more felt when the coil is placed on a short circuit, than when the line wire has itself considerable resistance: because, in the first case, a slight addition to the resistance of the coil

bears a large proportion to the total resistance of the circuit; while in the latter case the proportion would be but small, and the increased resistance small also.

When a line wire is very long, the current will necessarily be feeble, and the coil should consist of *fine* wire, which occupies little space, and allows very many layers to be wound on without increasing the distance from the core too much; while its resistance bears too small a proportion to that of the rest of the circuit to reduce the strength of the current materially.

But when the line is short, each layer of fine wire would decrease the useful effect by adding to the resistance of the circuit, more than would be made up by the multiplying effect of the increased number of turns; for a few layers would double the resistance of the circuit, while a thicker wire would not materially enfeeble the current; and though, because of its size, the distance of each layer from the core rapidly increases, yet a sufficient number of turns may be employed without exceeding the distance at which the current acts with advantage.

The maximum power is obtained when the resistance of the coil is equal to that of the line and battery. This law may be acted upon for short lengths of line; in long lengths other elements enter into the calculation.

133. In winding galvanometers and electro-magnets, great care must be taken to preserve the insulation of the several turns of the wire, and especially to prevent metal filings from sticking to the covering, for they will pierce the silk and connect one turn with another, forming a "short circuit."

134. In electro-magnets, wound evenly over their entire length, the magnetism increases as the square root of the length; or if alike in all other respects, their power is proportional to the square root of the diameter of the core.

In four magnets, wound proportionally, 2, 4, 8, and 16 inches long, and respectively $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 inches in diameter, placed

at distances of 6, 12, 24, and 48 inches, the attractive force will be the same.[1]

135. A hollow core is less powerful than a solid one; but if its ends are made solid, there is no great difference. The poles of an electro-magnet should, therefore, never be smaller than the core.

136. The attraction between the electro-magnet and its armature decreases very rapidly as the distance between them increases; or, in other words, the attraction is inversely as the distance. When the armature is very near the core, the attraction diminishes as the simple distance afterwards as the square of the distance.

137. Iron will not take its full magnetism instantaneously, so that when the connection with the battery is made and broken rapidly, the core has not time to be *saturated*, and its attractive force will be but feeble. The act of demagnetization, or of losing magnetism, also takes time, but is effected more quickly than magnetization. The greater the tension of the battery, the more rapid the magnetization.

Thus, when very rapid action is required, even on short circuit, a considerable number of cells must be employed.

[1] Dub: as quoted in *Les Mondes*.

PART IV.

INDUCTION.

STATIC INDUCTION.

138. In addition to the power of communicating a *charge* of electricity by spark or contact, an electrified body exerts an influence on all conducting bodies in its neighbourhood, even if it has not been made to touch them, causing them to exhibit signs of electricity, which increase if they are made to approach, and diminish if they are removed from each other.

139. For instance, if an excited glass tube be made to approach the electroscope, the leaves will diverge; removing the tube, the divergence will decrease, and after a certain distance, depending on the degree to which the tube is excited, will disappear altogether.

140. This influence on conductors not in contact is called *electrostatic*, or *static* induction. It is an analogous action to that exerted by the magnet upon pieces of iron in its immediate neighbourhood, and is most readily explained by the so-called double fluid theory.

All bodies in nature are supposed to contain equal and opposite quantities of + and − electricity in a combined or neutral state. When an electrified body is brought sufficiently near an insulated unelectrified conductor, the neutral condition of the latter is disturbed, the two electricities are separated, the electricity of the *same* name (positive or negative) being repelled, and

that of the opposite name being attracted; so that it is divided into two parts, one of which is occupied by positive, and the other by negative, electricity; and however thin the body may be, even if as thin as a piece of gold leaf, its opposite sides will have contrary electricities, and the body will be *polarized*.

141. Take two insulated plates of metal, A and B, connect each to a separate electroscope (2); charge A, its electroscope will diverge; bring it near B, taking care that a spark be not allowed to pass between them, so as to charge B in the ordinary way; the electroscope connected with A will remain divergent, because the plate remains charged, and that of B will diverge, because of the induction exercised upon B by A (Fig. 39).

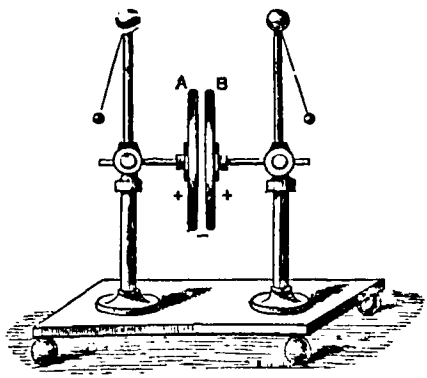


FIG. 39.

Separate the plates, A will remain divergent, but B will cease to show signs of electricity, because the inductive influence of A has ceased by its removal (Fig. 40).

The cause is this. If the plate A is electrified positively, and made to approach the insulated unelectrified plate B, its positive electricity attracts the negative of B to the side facing A, and repels the positive to the other side of the plate. When A is removed, the two separated electricities of B re-combine, and it regains the neutral unelectrified state, while A has neither gained nor lost anything by its action on B.

If, when the two plates are near each other, we touch A, we shall discharge it, and all electrical signs will cease in B also; for,

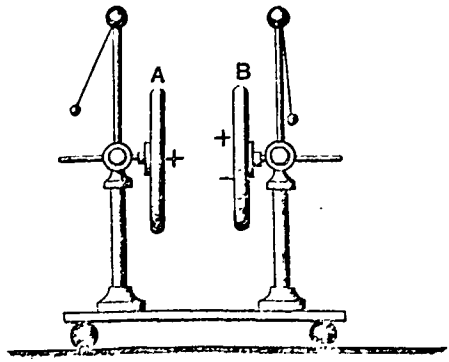


FIG. 40.

the inductive action of A upon B having ceased, the two separated electricities of B re-combine, and its neutral condition is restored.

If we touch B, while under the influence of A, we shall remove from the former so much of the *positive* portion of its natural electricity as has been repelled and separated by the inductive action of A.

But B will retain all its *negative* electricity, because it is attracted by the positive electricity of A (it is said to be *bound* or *disguised*), and the electrical state of B is for the time held in abeyance by that of A. The electroscope of B will cease to diverge because the opposite electricities of A and B expend their forces in attracting one another, leaving no force to be exerted upon the electroscope nor upon the finger; hence B cannot now be discharged. The electroscope of A would for the same reasons entirely cease to diverge, except that the charge of this, the *inducing* plate, is slightly greater than that which it has *induced* upon B, because a portion of it is expended in inducing a charge upon surrounding objects. Hence electroscope A remains slightly divergent.

Again, if we now touch A we shall not discharge it, because of

the inductive influence of B. In fact, the reaction of the opposite charges, in the two plates, prevents either being entirely discharged by a single touch, unless both are touched at the same moment, when the two electricities will entirely neutralize each other.

If the plates are removed beyond the distance at which they can sensibly act upon each other, the electroscopes both of B and A will diverge, for the two charges are now free to act on bodies within their influence, and therefore repel their respective pith balls or gold leaves. Either plate can now be readily and perfectly discharged.

142. The inductive action of our two plates is not only affected by their distance one from the other, but also by the nature of the substances which may lie between them. Thus if, when the plates are very near one another, a piece of glass be placed between them, the inductive effect will be greater than when air alone intervenes. A plate of shellac will further increase it, and sulphur will have a still greater effect. Each insulating substance, or *dielectric*, as it is called, has a natural property appertaining to itself with respect to induction, which is called its *specific inductive capacity*, and is the converse of its *specific inductive resistance;* the former being its power of *effecting* induction, the latter its power of *resisting* induction.

The specific inductive capacities of the chief insulating substances employed in telegraphy have been determined by Jenkin. Air being 1, gutta-percha is 4·2, Hooper's material 3·1, and pure india-rubber 2·8.

143. The two insulated plates, A and B, form a *condenser;* so called, because by such an arrangement we are enabled to *condense*, or accumulate upon a given surface, a greater quantity of electricity than it would contain were it not for induction.

When the plate A is submitted to the influence of the negative charge of B, the greater part of its positive electricity is attracted to the side nearest B. The tension of the opposite side of A is

now, therefore, less than that of the source from which it was charged, so that, if it is placed in communication with that source, it is able to receive a second portion of electricity. This will decompose a second portion of the electricity of B, the positive part of which passes to the earth when the plate is touched, as in the former case; A can now receive a third portion, and so on, until its tension becomes equal to that of the source.

A pane of glass, coated on both sides with metal foil to within an inch of its edge, will represent the plates A and B separated by glass. This forms a convenient condenser. A still more convenient form is the *Leyden jar* (Fig. 40*), a wide-mouthed bottle coated with foil inside and out three-fourths of its height. The foil on the outside may be considered as taking the place of B; that on the inside, the place of A. They are called the *outside* and *inside coatings.*

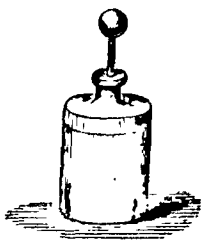


FIG. 40*.

Condensers may be made of plates of metal foil, divided one from the other by any good insulator. The thinner the dividing insulator, the greater the inductive effect or capacity.

The condensers used in telegraphy are made so as to expose a large surface to inductive action, and are constructed of alternate layers of tinfoil and thin plates of mica, gutta-percha, or paper saturated with paraffin, arranged like the leaves of an interleaved book—the metal plates being the printed leaves, the paraffin being the blank paper. Each *alternate* metal plate is connected so as to form two distinct series, insulated from each other; one of which may be connected with the object to be tested, the other with the earth.

144. The *capacity* of a condenser, or its power of storing up electricity, is proportional to the extent of the surfaces exposed to induction, to the distance between them, and to the specific inductive capacity of the insulating material used to separate them.

145. The *condensing electroscope* is useful for detecting electricity of very feeble tension, such as that of a small battery. It is an ordinary gold-leaf or Peltier electroscope, with two condensing plates attached, and may be roughly constructed in the following manner (Fig. 41) :—

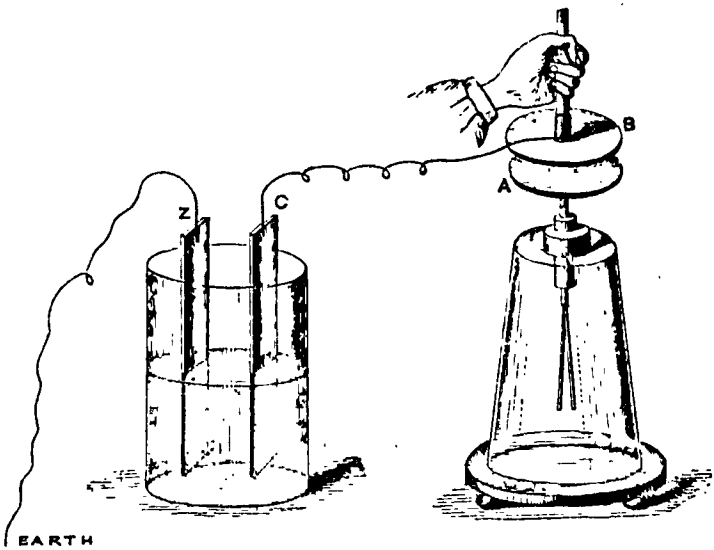


FIG. 41.

Cut out two discs of sheet tin, flatten them, fix one (B) on an insulating handle, attach the other (A) to the wire of the electroscope. Drop three small pieces of hot sealing-wax on A, so that, if B be placed on it, the two shall lie as closely together as possible without touching.

Place B upon A, connect B with the positive pole of the battery, it will receive a very feeble positive charge. Touch A with the finger, its positive electricity will pass to the earth, and B will be enabled to take up an additional quantity of electricity from the battery. Remove the finger from A, and, *after having done so,* lift off B by its insulating handle, the leaves will diverge. The divergence will be greater if the zinc plate of the battery is connected to the earth, than if it is insulated.

By this means the phenomenon of repulsion can be exhibited with one or two cells of a battery (21).

146. The *electrophorus*, a most convenient apparatus for obtaining electricity for experiments connected with telegraphy, owes its power to induction.

Procure a circular tin dish, similar to the lid of a canister, about 9 inches diameter and $\frac{3}{4}$ inch deep, fill it with melted sulphur, scrape or grind the surface perfectly flat, and paste a slip of tinfoil, 1 inch wide, over the edge of the tin and across the face of the sulphur. Make a wood disc, perfectly flat, of 7 inches diameter, cover one side smoothly with tinfoil, and fix upon the other side an insulating handle of varnished glass, or ebonite, by which the wood cover may be placed upon the sulphur cake with its tinfoil side downward.

If the sulphur and the wood cover be warmed, the former well rubbed with dry silk, cloth or flannel, and the cover placed upon the sulphur, when the cover is raised it will be found charged positively, and will give sparks each time it is replaced, touched and raised, for a considerable time. By the friction, the sulphur is excited negatively, its positive electricity passing to the earth.[1] When the cover is placed upon it, the electricity of the cover is decomposed by the inductive effect of the charged sulphur; the $-$ passing to the earth by the strip of foil, and the $+$ remaining upon the cover, being held fast by the $-$ of the sulphur. When the cover is raised, its charge is free to act again on surrounding conductors. The same effects recur as often as the cover is removed, until the excitation of the sulphur ceases.

147. Faraday assumes that all bodies are more or less conductors, and that they are composed of small and distinct particles, which in the unelectrified state are quiescent, but in the electrified state are *polarized;* that is to say, arranged so that

[1] The size of the earth being infinite, as compared with that of any electrical apparatus, its tension is unaffected by any quantity of electricity which can be added to it by artificial means.

their positive and negative portions are turned towards each other, this state being one of constraint from which there is a tendency to escape. If the particles can maintain this state for a sensible time, then some degree of insulation ensues; but if they cannot do so, discharge arises. This action is not instantaneous, but progressive from particle to particle, each transmitting the force to the one next beyond it.

A current is therefore caused in a wire by each successive particle undergoing induction and discharging itself to the next beyond it. The particles of a conductor offer very little obstacle to this induction and discharge, so that the current or transfer of force is carried on with extreme rapidity. In an insulator the progress is very slow, in some cases almost imperceptible.

148. When the wire is sufficiently near another conductor to be able to exercise an inductive influence upon it, this *exterior* induction must be completed by each portion of the wire before the current can pass on to the next.

When the wire is fully charged, it conducts precisely as if there was no induction, so long as the current is steady and regular. But if the current vary, its inductive effect varies also, and this change must be completed along the whole wire before the variation of the current can be transferred to the distant end.

When the battery contact is broken, the induction must cease in each successive section of the wire before it is fully discharged.

As these changes occupy a sensible time, they retard the passage of the current.

149. A wire supported on poles, when conveying a current, influences by induction the wires near it, and also the surface of the earth. But the distance between them is so great that the effect is extremely small.

If one pole of a battery is connected to earth, and the other to a line wire suspended on poles, well insulated and *disconnected*

at the distant end, a current will pass into the wire till it is charged; that is, till it has attained throughout its length the same tension as the battery.

If the battery contact be now broken, and the wire left disconnected, the charge will speedily be dissipated through the air and by leakage at the supports. But if the wire be put to earth at the sending end through an electro-magnet or galvanometer, immediately battery contact is broken a *discharge* will take place through the apparatus, as when the plates A and B are made to touch one another (141).

If the wire is short, the discharge will be completed before the apparatus has had *time* to move. The time occupied by the discharge increases with the length of the wire (other things being equal) until it attains sufficient duration to affect the apparatus. For the whole length of the wire must discharge itself at the one end.

150. For instance: if the key of a Morse instrument, connected to a long well-insulated wire, be pressed so as to charge the wire and be then allowed to fall back very suddenly, the dis-

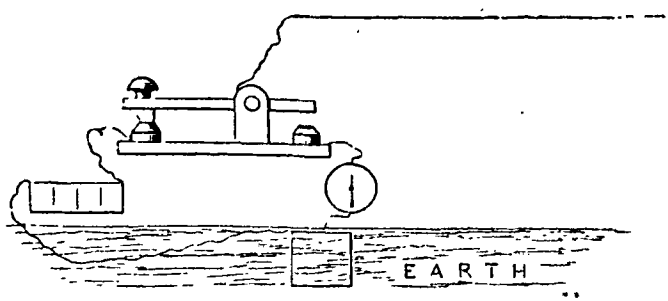


FIG. 42.

charge or *return current* will move the relay and produce a signal (Fig. 42). When the wire is very long, it is not necessary even that it be disconnected at the distant end, because the resistance is equivalent to partial insulation (12).

151. If the line wire is brought very near the ground, the

inductive action of the wire and earth will be increased, and the time of discharge increased also; and if it be covered with an insulator and buried, so that the distance is made exceedingly small, and the wire directly opposed on all sides to another conductor, induction, prolongation of current, and retardation of signals will be enormously increased, and the discharge or *return current* become very powerful. An immense Leyden jar or condenser has, in fact, been formed, having the wire for its inner, and the soil for its outer coating, which being in direct communication with the earth, like the plate B when touched with the finger, will part with the electricity set free by induction, enabling the wire to take up an additional charge from the battery. Each mile of ordinary coated copper wire (No. 16) has an inner surface of about 86 square feet, and an outer surface of 330 square feet. A hundred miles of such wire will therefore expose a very large surface.

152. Clark gives the following illustration in the "Submarine Report," p. 316, showing the similarity between a buried insulated wire and the Leyden jar.

Insulate a large tub filled with water, and place about half a mile of percha-covered wire in it.

Put one pole of a battery of 250 cells to earth, and connect the other pole through a key and galvanometer to one end of the wire, leaving the other end disconnected and well out of the water.

Place a copper plate in the tub, connect it by a wire to a second galvanometer, and put the other terminal of this galvanometer to earth. The water of the tub will thus be put to earth through the second galvanometer (Fig. 43). If a charge be sent into the half mile of wire by moving the key, electricity of the same kind will leave the water for the earth. Both the galvanometers will move in the same direction, precisely as if they were both in circuit, whereas the circuit is not completed. There will be this difference: in the case before us, the needles

will be affected for an instant only, however long we may press the key; while if the circuit were complete, they would continue deflected until battery contact was broken.

The water, which is the outer coating of the wire, and which takes the place of the plate B, is put to earth: Hence the portion of its electricity repelled by the charge given to the wire or plate A passes to earth, and an additional quantity passes into the wire from the battery (141).

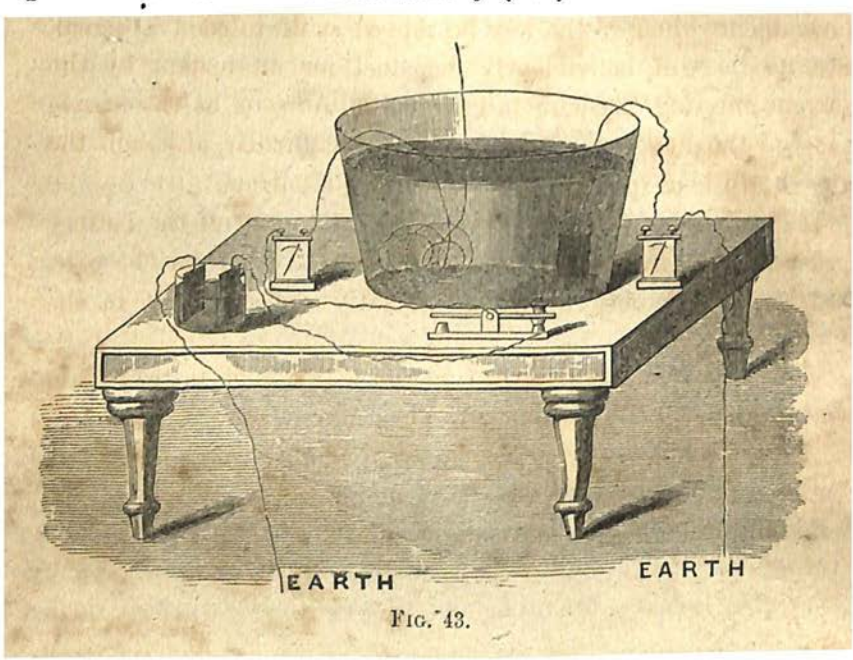


FIG. 43.

If the key is immediately pressed a second time, the same effect will not be produced, because the wire is fully charged. If sufficient time is allowed to enable part of the charge to escape, the galvanometer will, upon pressing the key, be again deflected by a quantity passing into the wire, equal to that which had leaked from it; and the deflection will be a measure of the amount of leakage.

If the battery is disconnected from earth, and the wires marked *earth* in the drawing are connected to that pole of the

battery which previously was to earth, exactly the same effect will be produced. A quantity of electricity will be transferred from one pole to the other. Two yards of covered wire, in a vessel filled with water, will show these effects well, if a reflecting galvanometer and 500 cells of a Daniell battery are used.

153. If 100 miles of covered wire be placed in water, one end insulated, the other end connected through an ordinary needle instrument to earth, and a battery of 40 or 50 cells joined to the instrument; then, if the key be moved as if to send a signal, the needle will be violently deflected for an instant by the current entering the wire to charge it. As soon as the wire is charged the needle will regain the perpendicular, although the key is still held in a position for sending a current.

If the handle be placed upright, so as to cut off the battery and put the wire to earth, the charge will rush from the wire, and the needle will again be violently deflected, but in the opposite direction.

Now, if the wire had been lying on a dry floor instead of in water, the needle would scarcely have moved, however powerful the battery; for though a current would enter into and charge the wire, the effect would be slight, and last too short a time to do more than barely move the needle.

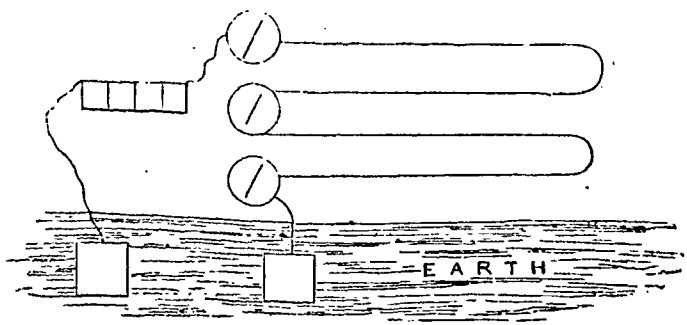


Fig. 44

Similar effects will arise if the wire is connected to earth at the distant end, but they will be less marked.

154. If two lengths of 100 miles, or more, be placed on a dry floor, and if a needle instrument be inserted between each length, and one at each end, so as to form a circuit (Fig. 46), when signals are sent in the usual manner, all the needles will move sensibly at the same time, sharply and distinctly.

But if the wire be put in water, or buried in the ground, and the circuit be completed through the earth in the usual way, the needle at the battery end will move immediately the handle of the instrument is turned; the second needle will not move at the same instant, but a perceptible time afterwards; the third needle later still; and so on, showing that the current now travels more slowly than before.

In a line of 1,500 miles the distant galvanometer was not affected till after *two seconds.*

When the handle is caused to break battery contact and put on the earth, a discharge will take place, and the needles will fall back one after the other, commencing with that at the battery end.

155. To use a homely illustration, it may be said that we must *fill* (charge) the wire with electricity before a signal can be sent, and to reverse a signal we must empty it, and refill it with the opposite electricity. A suspended wire soon empties itself, a portion of its charge escaping at each support, but a well-insulated buried wire cannot part with its charge anywhere except at the two ends. Hence a slightly leaky buried wire can be worked faster than one which is perfect, and a long and very perfectly insulated suspended wire, retards the extremely rapid signals of an *automatic* telegraph.

156. Induction is thus the cause of *prolongation of current* and *retardation of signals* in cables and underground wires. On a Morse printing circuit, the marks "run together" from the spaces between them being filled up by the current passing out from the cable after the battery contact has been broken.

On a needle circuit the sending needle is jerked violently in the reverse direction after each signal, and frequently becomes

demagnetized or cross-magnetized by the discharge or return current. The receiving needle moves sluggishly, and the signals run together, so that a letter of three movements appears like one of a single movement sent slowly.

157. Reversing the current after each signal facilitates the discharge at the sending end, by neutralizing the charge with electricity of the opposite sign; so that there is not so much to escape at the receiving end, thus rendering the received signals much more distinct.

158. In testing a buried wire, or even a well-insulated suspended wire, the distance of a disconnection may be estimated by the quantity of the return current; for the longer the wire, the longer will be the time occupied in the discharge, the greater its quantity, and the larger the deflection of the galvanometer.

159. If two or three successive currents be sent into a long buried wire, they will travel on like waves independently of each other. It is even possible to produce alternate waves of positive and negative electricity; that is, to charge the two ends of a wire oppositely.

160. As a wire, even when most free from inductive retardation, takes a certain time to charge, the current will not attain its maximum strength till battery contact has lasted sufficiently long. The longer the circuit, the more firmly and slowly must the battery contacts be made.

DYNAMIC, OR CURRENT INDUCTION.

161. In addition to the effects of attraction and repulsion (112), a wire conveying a current exerts an influence upon other conductors near it, called *electro-dynamic* or current induction.

162. If two wires are placed near one another, but not in contact, one connected to a battery, the other to a galvanometer of sufficient sensibility, whenever a current is caused to pass through the former the galvanometer attached to the latter is deflected by a current flowing in the *opposite* direction to the battery current. The battery current is called the *inducing* or *primary* current; the other the *induced* or *secondary* current.

The *induced* current lasts but an instant; the needle falls back at once to zero, and continues unaffected so long as the *inducing* current continues to flow steadily. When battery contact is broken the needle is again moved, but now by an *induced* current flowing in the *same* direction as the battery current, and, like the former induced current, instantaneous.

While the current is flowing, should it be *increased*, or should the two wires be brought nearer one another, the inductive effect is similar to that of *making* battery contact: should the current be *decreased* or the wires *removed further apart*, the effect is like that of *breaking* battery contact. The action is greatest when the wires are parallel, and is null when they are placed at right angles. It is not confined to the extremities of the wires, but is equal throughout their entire length.

163. The effect in such a length of wire as can conveniently be arranged in a straight line is but feeble, but by coiling the wires into a spiral their length can be increased almost to any extent, and a very energetic action may be obtained. The wires must of course be covered with cotton or silk to insulate the several turns from each other.

164. Construct two flat spirals of covered wire by coiling them in a similar manner to a roll of tape (Fig. 45), lay one flat on a table, and connect its ends to a galvanometer: call this the *secondary* or *induced* spiral.

Connect the other spiral to a battery, and call it the *primary* or *inducing* spiral. If the second spiral be now laid upon the first quickly and smartly, the galvanometer needle will be

deflected for an instant; if it be quickly removed, the needle will be instantaneously moved in the opposite direction; but in neither case will the deflection of the needle be lasting.

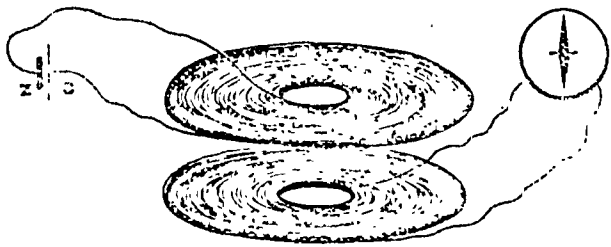


FIG. 45.

If battery contact be broken while the spirals are lying one on the other, the same effect will be produced as if they had been separated, and the restoration of battery contact will produce the same effect as that of placing one upon the other.

Again, if the spirals are suspended face to face, but not quite touching, they will attract one another if currents are caused to flow through both in the same direction, and will repel if the currents flow in opposite directions.

165. Currents are excited in the spiral connected to the galvanometer by employing a permanent magnet, instead of the inducing spiral, and causing it to approach or recede.

166. A still more powerful effect is produced by winding the wires upon bobbins made to fit one within the other (Fig. 46), and the effects of approach or removal are the same as with flat spirals. If the two wires are wrapped side by side upon the same bobbin, one will influence the other when the current commences, ceases, or varies.

167. Connect a hollow bobbin wound with covered wire to a galvanometer, and rapidly place the pole of a magnet just within the hollow: the needle will move, and immediately fall back to zero. On removing the magnet a similar movement will be produced, but in the opposite direction.

If the other pole of the magnet be employed, the currents will be reversed.

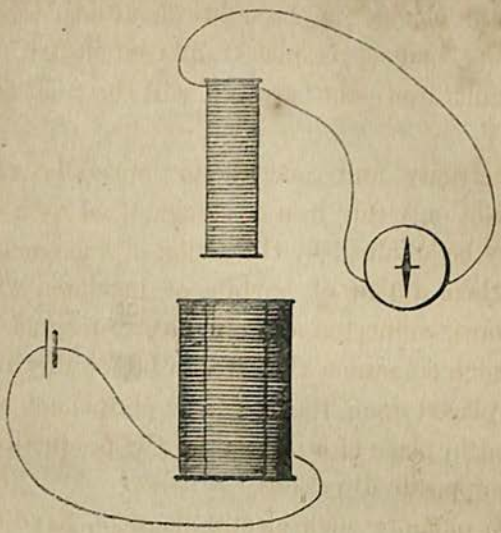
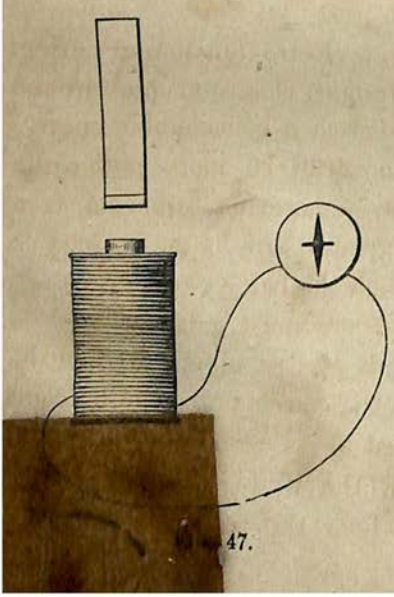


FIG. 46.

168. Place a bar of soft iron within the bobbin, and bring a pole of a bar magnet near it (Fig. 47); the iron will be magnetized by induction, and the currents will be much more powerful, because in this case the effect of the increase and the diminution of magnetism in the iron will be superadded to that of the approach and withdrawal of the permanent magnet.



47.

169. These currents are but momentary; they exist only during the time the magnetic change is taking place; and the direction of the current produced by the *cessation* of magnetism when the permanent magnet is

removed, will be the reverse of that set up by its *production* when the magnet is caused to approach. The more rapidly the magnetic change is brought about—that is, the more promptly the magnet is placed in contact with or detached from the soft iron—the greater will be the tension of the current.

170. Electricity and magnetism mutually reproduce one another. Not only can iron be magnetized by a current, but a current may be obtained by the action of a magnet.

171. If, then, a pair of bobbins of insulated wire containing soft iron cores, connected as in an electro-magnet, is fixed upon a lever in such a manner that it can be forcibly detached from, or quickly placed upon, the poles of a permanent magnet, it may be employed in place of a battery for the production of transient currents in opposite directions.

172. Two or more such electro-magnets, fixed on an axis so as to revolve in front of a series of permanent magnets, form a more powerful arrangement; and by a proper arrangement of switches or commutators, the two sets of currents may be made to flow in the same direction through a wire connected to the apparatus.

173. The most powerful effects of electro-dynamic or current induction are produced when a straight electro-magnet, wound with a thick wire, is again wrapped with a considerable number of layers of finer wire. The core can be more powerfully magnetized by a current than by a permanent magnet, consequently its inductive force is greater, and is superadded to that of the thick wire through which the battery current passes. To produce the greatest effect, the core must gain and lose its magnetism very rapidly; this result is best obtained when the circulation of induced currents in the core is prevented by composing it of a bundle of unpolished wires. The thick *inducing* wire is called the *primary* coil, the thin *induced* wire the *secondary* coil. The longer and finer the secondary coil, the

greater the tension of the induced current, and it is necessary to be extremely careful in its insulation.

174. A current exerts also an inductive action upon the wire through which it flows, called the *induction of a current upon itself.* Connect one of the poles of a battery sufficiently powerful to give a spark, to a mercury cup, and close the circuit by dipping a wire connected to the other pole into the cup. If this wire is short the spark will be comparatively feeble, but if it be lengthened the force of the spark will be *increased,* although the extra resistance introduced by the lengthening of the wire will have enfeebled the current. If the wire is coiled on a bobbin, or in a spiral, the spark will be brighter still, even if its length be not increased, because each turn acts inductively upon those adjoining it. When a soft iron core is introduced the effect is again increased, because the iron which has been magnetized by the current will, in losing its magnetism, tend also itself to produce a current in the wire, and in the same direction. Closing the battery circuit also induces a current in the conducting wire, but in a *contrary* direction to the battery current, so that the spark on making contact is the difference instead of the sum of the two currents.

175. The effect upon an electro-magnet is this. At the moment that a current commences to flow through the coils, it produces in the wire an induced current, lasting but an instant, flowing in a *reverse* direction to that of the battery, and opposing it so as to delay the magnetization of the core. Again, when contact is broken, the cessation of the battery current causes a second induced current, in this case flowing *direct,* or in the *same* direction as the battery current, and therefore prolonging its effect, so as to delay the demagnetization of the core; and by adding its force to that of the battery, causing the spark which ment contact is broken to be much more power- which occurs with a simple straight wire. They currents; the direct is the more powerful,

because its force is added to, while that of the inverse is subtracted from, that of the battery current. The *inverse* current exists during the time the magnetism of the iron is *increasing*, the *direct* current while it is *decreasing*.

176. The extra current direct can be well seen in the coils of gutta-percha-covered wire in a cable factory. They are generally a mile in length, and are coiled upon iron reels, so as really to become electro-magnets. If the reel is put into water, or if one end of the iron is insulated, and the other is first connected to a battery so as to charge it, and then quickly put to earth through a galvanometer, the needle is deflected by the usual inductive discharge.

But if the distant end is put to earth, and the coil then charged and quickly connected as before to the galvanometer, the needle is deflected in the *opposite* direction, and to a far greater extent. The earth in this case acts simply as a conductor in connecting the distant end of the coil with the galvanometer, and thus forming a circuit for the extra current. The same occurs in an iron-sheathed cable coiled in a tank. A similar effect is observed if the wire is not wound on an iron reel, but here the extra current is very feeble.

177. When the two extremities of an electro-magnet coil are connected by a wire, so as to afford a circuit for the extra currents, the demagnetization of the core is so much impeded, that when battery contact is made and broken rapidly the armature remains attracted. This principle has been employed in the construction of translators.

By connecting the ends of the coil to a condenser (143), the iron is demagnetized more rapidly, the spark is considerably lessened.

The *extra* current enters the condenser instead of darting across from one extremity of the coil to the oth

178. The commencing and ceasing of t
electro-magnets also give rise to induced curr

iron core or in the metal bobbin of the coil. To prevent the formation of these currents, which are injurious inasmuch as they delay the action of the battery current, it is only necessary to destroy the path in which they are able to circulate: this is effected by slitting the metallic bobbin in the direction of its length.

PART V.

ATMOSPHERIC ELECTRICITY AND EARTH CURRENTS.

ATMOSPHERIC ELECTRICITY.

179. THERE is always free electricity in the air and in the clouds, acting by induction upon the earth and the wires, and creating an opposite tension in them. If the electrical condition of the atmosphere were constant, that of the wires would remain constant also, as far as regards their mutual influence. But it is not so.

When an electrified cloud approaches the wires, it charges them by induction; this charge escapes in sparks at the apparatus, demagnetizing or reversing the magnets, or fusing the coils, even although there may be no actual lightning. No case has, however, occurred in which the person in charge of the apparatus has been injured; for the instruments afford the current a much more ready path than that given by the human body.

180. During a storm, the instruments should be placed on short circuit by connecting their line terminals across; and if the lightning be very vivid, it may be best to disconnect them, putting the line direct to earth.

In situations much exposed to lightning, some form of *paratonnerre* or protector should be used, and invariably at the ends of long pieces of underground work or cables. But they must always be placed indoors, or it will be impossible to preserve their insulation. So very few accidents occur from

lightning in this country, only about 3 per cent. per annum of the instrument coils being fused, that it was for a long time considered undesirable to use protectors universally, for they are apt to interrupt the communication.

Tying a knot in the fine wire of a coil will often cause the spark to jump to the metal frame, and thus preserve the coil from destruction.

A very simple and efficient protector for moderate discharges may be made by twisting together two pieces of wire well covered with silk, enclosing the twisted portion in a little tube, and filling it with paraffin. The two wires should differ in colour to show which is which. It may either be placed in the circuit of the coil wires or between the line and earth outside the coils.

One of the best and simplest protectors consists of two flat brass plates, each having a surface of about ten square inches, placed one upon the other, separated only by a piece of paper soaked in paraffin. Guillemin proposes mica, which, he says, is better than paper, because it is not carbonized by the spark, so as to make earth, as paper will sometimes do.

The *vacuum* protector, consisting of platinum wires connected one to each of the line wires and one to the earth, sealed in an exhausted glass bulb, answers perfectly. The lightning generally destroys the bulb, but does not reach the cable. Another efficient form is two metallic points, placed about $\frac{1}{8}$ of an inch apart, in a small wood cylinder, filled with a semi-conducting powder containing carbon.

181. When a discharge takes place between the clouds and the wires—that is, when the lightning strikes the wires—the charge escapes by the poles, splitting them. The line wires are sometimes, but rarely, fused. The leading-in wires should not be allowed to pass too near lead gas-pipes, lest a spark should dart [illegible] and fuse the pipes, as has occurred in one [illegible]. For a similar reason an *earth* should never be [illegible] gas-pipe.

182. As long magnets retain their power much better than short ones, it is desirable not to use very short needles in signal instruments, where reversal might be dangerous.

It is better, indeed, to use soft iron needles, *induced* by a large magnet.

EARTH CURRENTS.

183. Occasionally, especially during the aurora borealis, strong currents, sometimes steady, at other times changing from positive to negative very rapidly, appear in the wires. These currents are not caused by atmospheric electricity, for they cease if a wire be disconnected at one of its ends, and they appear equally in buried and in suspended wires. They seem rather to be caused by currents flowing from one part of the earth to another, which enter the wires by one of their earth connections and leave them by the other.

Lines running north-east and south-west are most frequently affected; lines lying north-west and south-east are not often disturbed, and, if affected, the currents are weak. It seems also, that the direction in which the current flows changes with the hour of the day, so that one line may be more strongly affected in the morning, another in the afternoon. The current has frequently been seen to leave one circuit and to appear upon another previously free.

184. The direction of the current is not determined by the actual course of the wires, but by that of a straight line drawn from one extremity, or earth-plate, to the other, modified by leakage to earth from bad insulation or *faults*, and sometimes also by the character of the soil, as affecting its conducting power. These currents are almost always passing; but it is only occasionally, during what are called *magnetic storms* or auroras, that they are sufficiently powerful to affect the telegraph, except

by interfering with tests for the resistance of the wires. The currents are sometimes as powerful as that from eighty cells of the battery *on short circuit*, and will give sparks. The longer the line the stronger the currents, other things being equal. They have a *direct* effect upon the magnet without the aid of a conducting wire, so that the delicately suspended magnets of a magnetic observatory, and even the magnet of a Thomson galvanometer, are moved by them; and where the movements of the suspended horizontal magnet have been compared with those of a galvanometer, connected to a telegraph wire, the two have sensibly coincided, showing that both are due to the same cause.

185. It has been observed that when an aurora presents a steady glow, the currents are to some extent uniform in direction, but that when streamers appear they vary very rapidly from positive to negative.

186. When communication is stopped on a needle instrument, it is possible, when the currents do not vary rapidly in sign, to restore it by the use of a magnet, but this method is seldom satisfactory. The only efficient method is to abandon the use of the earth-plates at terminal stations, and to form metallic circuits. This can always be done when there are two wires which can be connected in loop. It is not absolutely necessary to loop the wires at more than one station. In some cases condensers may be placed in the line wire, between the line and apparatus, so that the wire is completely insulated; this method is adopted in the Atlantic cables, which from their direction are peculiarly affected by the currents.

Where there are not two wires, the circuit may be extended by connecting another to it, the terminus of which is so situated that a line connecting it with the terminus of the first lies out of the direction of the current at the time. If there are two circuits on which the earth currents are generally opposite in direction, but equal in force, these, when connected so as to form [illegible] free from disturbance.

These methods succeed best when the wires are well insulated, because any cause which brings them into connection with the earth permits the earth current to flow through them.

187. These *earth currents* must not be confounded with the *earth battery* current set up between two dissimilar earth plates, or with the current which sometimes is set up when the conductor of a cable or buried wire is in contact with earth at a fault.

188. In the United States, where the "closed circuit" principle is extensively used, it has sometimes been found possible to detach the batteries, and to work with the earth currents so long as their force remains uniform.

PART VI.

INSULATION.

189. When a wire is suspended on poles it is fixed to *insulators*, to prevent the escape of the current at the points of support. When it is carried through wet tunnels, underground, or through water, the insulation must be *continuous*, and the wire is covered with gutta-percha or india-rubber.

190. The insulation of an overground line is never perfect, even in dry weather. There is a loss at every point of support even when the insulators are clean, and this is considerably increased when their surfaces are damp, more especially so when dusty, dirty with smoke, or covered with salt from being near the sea. When the wires are not galvanized, a slight coating of rust is formed upon the insulators by the rain dropping from the wires, which is injurious. The wires are often hung with spiders' webs, which, when covered with dirt and moisture, conduct; and on a long line the leakage from wire to wire, from this cause alone, cannot be altogether without effect. A very rough test will show how much insulation is affected by dirt or smoke, and too much care cannot be taken to keep the insulators clean.

191. As damp affects insulation so seriously, great care was taken in the earlier telegraphs to protect insulators from the rain by wooden roofs; but it has been found that such coverings are not only useless, but injurious. They do not themselves insulate, they afford no protection in fogs or continued rain

for then every part becomes equally damp. They harbour spiders, which spin their webs over and among the wires. They hinder the drying of the supports, and prevent the rain washing off the dust which covers the insulators. The inside of a hollow insulator, or that part which is protected by a wooden arm, is always dirtier than those parts which are fully exposed, and damp dirt conducts far better than a film of dew or clean rain-water. Insulation is frequently improved by a heavy summer shower. There is therefore a great disadvantage in placing insulators under bridges, where they are quickly covered with smoke, and are hidden from the cleansing effect of rain. The umbrella-shaped insulator secures all the advantages of the roof in keeping an insulating surface dry in moderately wet weather, while it adds to its insulating power by increasing its length.

192. Complete exposure is most of all desirable on the sea-coast. It is true that a cover may protect an insulator from the effects of spray, but during storms the air is impregnated with water holding salt in solution, and this, when evaporated, lines the insulator inside and out with a thin layer of salt. If all the surface of the insulator were exposed, the next shower of rain would wash away this coating; but if covered the salt would be left, and the insulator would gain considerable conducting power with the slightest damp. Iron hoods are, therefore undesirable, and should never be used except where they are absolutely necessary. They may be made with slits, so as to admit the rain and wind, and prevent the accumulation of dust. It is, however, so difficult to secure the insulation of a coast line, that the sea should be avoided as much as possible.

193. In order to form a correct conception of the relative merits of various kinds of insulators, it is best to consider them not as *insulators*, but as *conductors*, whose value depends on their resistance to conduction.

The conduction of currents through wires and metals occurs

through the mass or thickness of the materials, and is therefore a question of bulk or weight; but the resistance of insulators is almost purely a question of surface, and in insulators similar in other respects, the largest in diameter and shortest in length will conduct best, following the ordinary laws of resistance.

The best insulator is that which has the smallest possible diameter consonant with strength, with the greatest distance between the wire and the bolt or support; and which can be maintained in the driest condition in wet weather, while exposed freely, as regards its outer surface, to the cleansing action of rain.

Length is most easily given by a form like that of two cup-shaped insulators, placed one inside the other. A tube or double cone surrounding the wire and supported at its centre, and a *shackle*, must be *double* the length of an insulator fixed at its ends (such as an invert) to be equally effective; because the current escapes from the wire at each end of the insulator in the former, and at one end only in the latter case.

194. The affinity of a material for moisture, or its power to attract damp, is an important point. Glass, though a better insulator than porcelain, becomes damp much sooner. If a glass tumbler and a tea-cup, each filled with cold water, be brought into a damp warm room, the glass will be covered with dew long before the porcelain shows any signs of moisture. The glass supports of apparatus used for experiments on frictional electricity must be varnished with shellac, to lessen this affinity for moisture.

Cast glass has been very extensively used; but out of the hundreds of thousands of insulators put up fifteen years since, very few remain. It is probable that want of care in annealing may have been a principal cause of this failure; but even if due attention in this respect would render it more to be depended on, it is next to impossible practically to find out if the annealing be perfect or not, and glass at its best is but fragile and

treacherous. It is, however, largely used in Switzerland. Glass insulators break very rapidly in those deep railway cuttings into which the sun does not shine till late in the morning, so that, instead of being warmed gradually, they are heated suddenly at a time when the sun has attained great power.

195. It has often been observed of electrical machines, that a cylinder has more power, and works better in a room, than a plate. Snow Harris considered that this arose from the nature of the surface of the glass, and found that a plate machine constructed of several layers or thicknesses of window glass cemented together was as efficient as a cylinder, because window glass is blown, not moulded or cast. Reasoning from this, Mr. Brooks, an American, lately introduced a blown glass insulator in the form of a narrow-necked bottle. It certainly gives very good results as regards insulation—indeed, as far as trial tests go it is superior to all materials except newly polished ebonite. He considers it owes its effect to what he calls an "air surface," that is, to a surface which has not come into contact with anything but air, while hot.

196. Ebonite insulates much better than glass, and is far less apt to become damp than even porcelain. It is the best material yet known for the insulation of electrical apparatus. Compared with porcelain or earthenware, it less easily becomes wet in mist, but more easily in rain. Rain forms detached drops upon a surface of earthenware, but covers ebonite with a continuous film. Thus the latter acts with most advantage when it forms the inner cup of a compound insulator, and is protected by earthenware from the direct action of rain.

The surface of ebonite becomes rough and spongy, so as to retain dirt, and it matters not how perfect the *substance* of the insulator may be if its *surface* is defective.

The change extends only to a very thin film, so that when repolished, it behaves as well as at first. This shows conclusively the effect of surface.

197. For many purposes it is most excellent. An insulator may be made small and light, and will yet be sufficiently strong not to be broken accidentally or by the strain of the wire. For this reason it will afford a uniform, although perhaps not a very high insulation. This is an advantage which cannot be overlooked.

Moreover, its very colour, and the unpretending appearance of a small insulator, protects it greatly from wilful damage, and would be an advantage in wild countries. It is found that where the telegraph is exposed to mischief, a large white porcelain insulator is quickly broken; earthenware is less attacked, and a small ebonite insulator not at all. Mischievous boys and others cannot hit the small mark with stones, and it does not tempt them by its inviting appearance. Many who would not take the trouble to break an unpretending black cup, could not resist the temptation of throwing at a large white one.

198. The best material for an insulator is a really good porcelain, thoroughly vitrified, so as to insulate perfectly even when unglazed. Its value arises principally from its polished smooth surface, which resists the formation of a continuous film of moisture, does not retain dust, and is washed clean by rain.

The objection to porcelain is, that considerable skill is required to select it, and to distinguish between a good and an inferior sample. As it is a compound of several substances, it is difficult to secure uniformity of composition, and much is left to the care and honour of the manufacturer.

Though a *good* glaze does not deteriorate by age or exposure to the weather, it is difficult to distinguish between a good and a bad glaze by inspection or electrical test, and it is quite possible that a glaze which *appears* good and insulates well may crack by age.

199. Brown stoneware is both excellent in quality, cheap, and durable. Its surface is not equal to that of porcelain, so that it

never insulates so well as the best specimens of the latter, but the glaze never cracks. Again, it is not a compound; so that when a manufacturer possesses a suitable clay, and takes care in its preparation, the uniformity of his ware may be depended on. It is also comparatively easy to distinguish its quality, and to detect faults in its manufacture.

200. Small pieces of ware are more easily burned, and therefore more likely to be perfect, than large ones. There is therefore a great advantage in forming an insulator of separate hollow pieces or cups, placed one inside the other and fastened with cement: if one is defective, there is a probability the others will be sound; and if the pin or bolt be covered with an insulator (such as ebonite), insulation will not be destroyed if the earthenware be entirely useless.

201. Insulators should be tested before they are sent out from store. It is best to test the separate pieces before they are put together. A trough lined with lead is fitted with a rack to fit the porcelain cups; the cups are arranged mouth upwards, and the troughs filled with acidulated water to within half an inch of their edges. The edges are slightly smeared with grease, paraffin, or turpentine, to prevent the water spreading over them, and the cups are nearly filled with water.

One pole of a battery of 250 Daniell cells is connected to the lead of the trough, the other pole to an insulated handle, a very delicate galvanometer being placed in circuit. The conducting wire is dipped into the water contained in each insulator in rapid succession, and if any one is faulty the needle moves. The acid must be very carefully washed off after the tests. From its power of repelling water, grease greatly aids insulation; paraffin, again, enormously improves it; so that in testing samples it is necessary to ascertain carefully that they have not been coated with these substances.

202. In order to learn the comparative value of different kinds of insulators, they should be fixed upon standards exposed

to the rain equally on all sides, and tested when the weather is uniformly wet. Almost any insulator will suffice in fine weather, while that which tests best in slight rain may not give the same result in extreme wet, when the insulation is most tried.

The best method of testing is to fix as large a number as convenient, certainly not less than ten of each kind, upon a pole, connecting them by a wire to represent the line wire, and fixing a second independent wire to their bolts, to represent the earth, and to determine the leakage from one wire to the other.

To obtain good results the following precautions are necessary. Fix a pole not less than 20 feet high in an open place not sheltered in any way or on any side, place the arms on which the insulators are to be fixed at least two feet apart, the insulators themselves a foot apart. Do not place all of the same kind together, but rather alternate or mix them as much as possible, so as to obtain an average of exposure for all.

Take special care that the wire representing the line touches each one closely all round and uniformly as to the number of turns: let it be all the same gauge. The object is to ensure equal surfaces of metal in contact with the porcelain, because the leakage takes place from each point of the wire over the surface of the insulator, and consequently if the wire does not touch uniformly, the leakage will vary with the variation of the surfaces in contact. If possible, divide each set of ten in half, making duplicate sets of five each. If these do not test alike, there is probably a defective insulator among them, which will vitiate the test and must be removed. Never use separate gutta-percha or other insulated leads from each set to the testing room, for these will become more or less damp on their surface and will vary in insulation, one from the other, more perhaps than the insulators themselves. Use only one wire, employing a man to shift it from one set to the other.

It is seldom that rain falls steadily and uniformly, so that if the testing lasts even five minutes there will often be considerable difference in the amount of moisture during the interval. After testing all the sets, commence again in the reverse order; if the two series agree, the observation is a good one. As the object of such tests is not so much to find the *absolute* resistance of the several specimens as to ascertain their *relative* value, it is better not to occupy time in testing in units, but rather to read a simple deflection so that the tests may be made as rapidly as possible, ensuring the greatest possible uniformity of circumstances; but with the greatest precaution, the tests will frequently be extremely anomalous.

203. Speaking generally, the best insulator is not that which tests best when quite new, but that which bears exposure the best, and therefore no tests are of any value which have not extended over several months. However carefully this experimental testing may be conducted, it is not altogether satisfactory; the only true method is to insulate two wires on the same poles for a distance of ten miles or more, and to test them every damp day for six months. It is useless in any case to test in dry weather.

204. The following is the result of tests made in a situation quite free from insects, but somewhat smoky—Gloucester Road, Regent's Park—during 12 months, 1868-9:—

Mean Comparative Loss.

Brooks' double cup (*American glass*) . .	5	parts	leakage.
Varley's brown ware	20	„	„
Porcelain	26	„	„
Double cones, porcelain	51	„	„
Shackles, ditto	82	„	„

The porcelain insulators were very much wider than the Varley's, to render them less liable to be blocked up by insects.

The test, therefore, does not show the difference between stoneware and porcelain so much as that between a wide and a narrow opening.

Two wires on a railway were insulated, one with Brooks', the other with Varley's—there were 44 of each. On a very foggy night the insulation of the former was 290,000, of the latter 150,000 ohms; but the following morning, just after the sun broke out, Brooks' tested 390,000, Varley's two millions.

The effect of iron caps may be judged from the following:—

Porcelain, without caps	38	parts	leakage.
„ with open caps (or cages) . .	44	„	„
„ with closed caps	55	„	„
Small earthenware insulator, without caps	50	„	„
„ „ „ with open caps	50	„	„

The tests also show that, with a wide cup, a bracket gives a better result than an arm, probably because splashing is avoided; the leakage being 26 and 38 respectively.

205. Periodical cleansing is very necessary. The interior of the umbrella or cup is a favourite resort of spiders, which spin their cocoons and deposit their eggs within them. Straw and dirt adhere to the web, so as, in some places, especially under trees, completely to fill the hollow and destroy the insulation. It is therefore well to choose the late autumn for cleaning, because of the spiders, as well as on account of the coming winter.

In practice a long and narrow single cell gives a better insulation than a double cell of half the depth.

If the line pass through an open country free from trees, the openings may be narrow; but if it pass near or under trees, they must be wide, less liable to be bridged across, and more easily cleaned. In the high roads of Ireland insects are very numerous and troublesome. In India, it is said that, however large an

insulator may be, an insect of the proper size is always ready for it.

206. After a long succession of dry weather, inland lines become so much coated with dust, that on the first damp day of autumn, before actual rain has fallen, the insulation is lowered and communication becomes very difficult, as much so, perhaps, as at any time, except during an exceptionally violent storm of wind and rain. When rain falls, the difficulty at once vanishes.

207. For a short line a small, simple, and cheap insulator will be amply sufficient, and its maintenance need not be very carefully looked after.

For a long line the best insulators must be used; they must be kept clean, and carefully renewed when broken.

208. New insulators may be dipped while dry and hot in melted paraffin with excellent results, but it is not certain whether the surface may not retain dirt more easily.

Washing or smearing with paraffin oil is an excellent method of improving insulation for a time; the effect lasts about six months.

209. Spiders will not build on creosoted poles, nor in those ebonite insulators which have been varnished with a solution of ebonite in naphtha to improve their surface after it has become rough. But the repelling effect ceases as the smell passes off.

210. In very smoky places it is perhaps better to change the insulators occasionally, for the dirt adheres too firmly to be removed by ordinary washing.

211. When insulation is imperfect, when the wires touch the ground, a wet wall, the boughs of trees, grass, or the like, part of the current escapes to the earth. This *fault* is technically called "*earth*."

Imperfect insulation also allows the current to divide itself between all the wires on the pole in proportion to their

respective resistances; and as the shorter the wire the less the resistance, the tendency is to escape from a long circuit into a short one. The current divides in like manner when the wires touch one another, or are connected by wet cotton waste (which is often thrown on them by engine-drivers), by kite-strings, or other conductors. This *fault* is called "*contact;*" and when it arises from the effect of bad weather on defective insulation, "*weather contact.*"

212. When the current escapes to the *earth*, the signals are simply weakened, and the loss can be made up by increased battery power; but when it leaks into *another wire* it confuses the signals passing upon that wire, and when signals are sent on the second wire the current interferes with that passing on the first wire. If the battery power is increased to make up for the loss of current, the interference is increased also. Thus "*weather contact*" is a far more serious evil than leakage to the earth.

It is an advantage, therefore, if the leakages can be intercepted and conveyed to earth by placing an earth circuit between wire and wire. The signals will, it is true, be weakened; but the loss of current may now be compensated by increasing the battery, without affecting the other circuits on the poles. To obtain the best result, these earth wires should be soldered to the insulator bolts or to the iron bracket holding the insulator, which is provided with a tinned iron pin for this purpose; the earth wire must be attached to the bracket after the latter has been fixed to the pole, and it is very much easier to solder to the small pin than to the mass of the bracket. If the wires are not soldered to the insulator bolts, they should, at all events, be tightly screwed between the nut and washer.

From the main thick wire which is fixed to the side of the pole, branches of binding wire are carried to the several insulators.

When wood arms are used, and it is considered desirable not

to lose the insulation afforded by the wood, the earth wires may be wrapped closely round the arm, or sunk in a saw groove, but they must be placed as close to the pole as possible, so that if a wire fall on the arm it may not touch them. They are screwed tightly between the head of the bolt by which the arm is fixed and its washer, so that the leakage through the wood, as well as that over its surface, may be conveyed to earth. The wire obviously must not be covered with paint or tar. This method is not so effectual as the first, nor is the insulation of the wood of much service in wet weather.

When a single line wire is carried on the pole top, it is not necessary, indeed not desirable, to fix an earth wire to it; because its leakage cannot pass into the other wires, being intercepted before it reaches them; while its own support being fixed on the end grain of the wood, makes good earth through the pole.

213. These earth wires, however, do much more harm than good when they do not make "good earth;" that is, when there is any resistance between them and the earth. To form a good earth connection, it is well to attach a thick wire to the pole and to coil it in a spiral under the pole-foot, taking care, of course, that it does not become tarry. When poles are set in rock or on viaducts, these wires must not be used. If, however, there be special reasons for protecting such places, let an uninsulated wire be run from pole to pole, and put to earth at the nearest and most convenient place.

When rain occurs after a long drought, it sometimes happens that there is more weather contact on the first wet day than afterwards. The soil is dry, and the earth wires are partially insulated. They do not make good earth until the soil has become damp.

214. If these wires are carried to the top of the pole, and made to project above it, they form useful lightning conductors.

215. If a wire lies on the metals of a railway, or other perfect

conductor in communication with the earth, the resistance of the fault being nothing compared with that of the wire beyond it, all the current will pass to the earth, and none to the receiving station. This fault is called "*dead earth.*"

216. If the wire lies on the ground, touches rusty metal, or any other *imperfect* conductor in communication with the earth, the fault will offer more or less resistance, and is technically called "*partial earth.*" The greater the resistance of the fault the stronger will be the current which passes on to the receiving station, and *vice versâ.* The same occurs when two wires touch, or are in contact; thus a *contact always gives earth.*

217. The effect of a fault, whether earth or contact, is to decrease the resistance of the circuit, to work the batteries harder by augmenting the current passing out to the line, and to decrease the current received at the distant station.

But its effect on the signals will depend on its position on the line, and this position will determine also which of the two terminal stations shall be most inconvenienced by it, for a fault which prevents B reading A, may not prevent A reading B.

218. Let A B be a wire on which A is the sending and B the

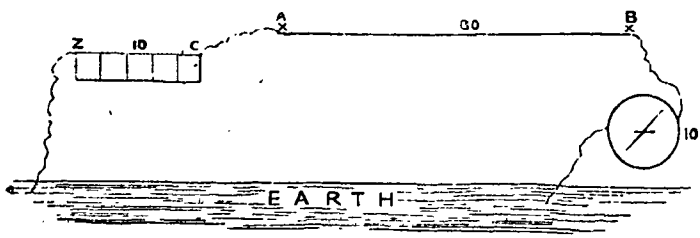


FIG. 48.

receiving station. Let it have a resistance of 80 ohms, and be perfectly insulated.

Place a set of batteries at A, having an electromotive force, E, of 1,000, and a resistance R of 10 ohms; connect one pole to the line, the other to earth. Place an instrument having a resistance of 10 ohms at B.

When perfect, the total resistance of the circuit will be—

80 ohms, line	}	= L
10 „ instrument . .	}	
10 „ battery		= R
100 ohms		= R + L.

In this case, in which the line is perfectly insulated, the entire current passing from the battery will act on the receiving instrument.

The force of the current, C, is found by Ohm's law to equal $\frac{E}{R+L}$. It will be $\frac{1,000}{100} = 10$. The strength of the signals, when the line is perfect, will therefore be 10.

Suppose, now, a fault to occur connecting the wire to the earth, and offering a resistance of 20 ohms. This will lessen the total resistance of the circuit in the same degree as if a wire of 20 ohms' resistance were fixed to the line at the fault, and connected to the earth; affording a second path for the current, which would split or divide at the fault into two parts, according to the resistance of the two routes open to it—the greater part following the shorter route. Thus, although the current passing out from battery to line will be increased, the strength of the signal will be decreased.

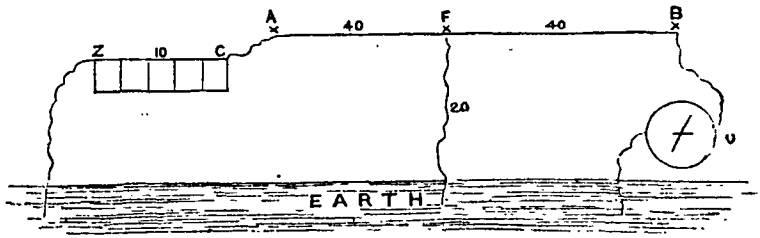


FIG. 49.

219. *First case.* Let the fault be in the centre of the line of . . . . . 80 ohms.

The two circuits beyond the fault will then be :—

1. That by the line and instrument, 40 + 10 = 50 ohms.
2. That by the fault itself . . . . . 20 „

Their joint resistance[1] will be $\frac{50 \times 20}{50 + 20}$ = ... 14·3

Adding the resistance of the battery, 10 ohms, and the wire between the battery and the fault, 40 ohms . . . . . 50·0

The total resistance will be . . . 64.3

and the current passing out to line $\frac{1,000}{64·3}$ = 15·5 parts instead of 10.

The two circuits between which the current will divide at the fault having, respectively, resistances of 20 and 50 ohms, are in the proportion of 2 to 5. If, therefore, the current of 15·5 be supposed to be divided into 7 parts, 5 parts will pass to earth by the fault, and 2 parts by the line and instrument. Thus $\frac{15·5 \times 2}{7}$ = 4·4, which will be the strength of the signal, instead of 10·0.

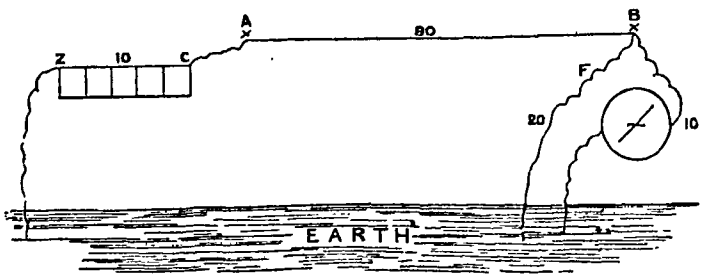


FIG. 50.

[1] The explanation of this formula is given in the Notes. The rule is—Divide the product of the two resistances by their sum.

Second case. The fault at the receiving station B. The two circuits beyond the fault will be:—

1. That by the instrument . . . = 10 ohms.
2. That by the fault . . . . . = 20 „

Their joint resistance $\frac{20 \times 10}{20 + 10}$ . . = 6·6 ohms, nearly.

The resistance of the entire circuit—

Battery	10 ohms.
Line	80 „
Instrument and fault	6·6 „
Total	96·6 ohms.

The current leaving the battery $\frac{1{,}000}{96{\cdot}6} = 10{\cdot}35$ nearly.

The two circuits at the fault having resistances of 20 ohms and 10 ohms, are in the proportion of 2 to 1, so that if the current divides into three parts, two parts will pass through the instrument; and the strength of the signals will be $\frac{10{\cdot}35 \times 2}{3} = 6{\cdot}9$ parts, instead of 10.

Third case. The fault at the sending station A. The two circuits beyond the fault will be:—

1. By the instrument and line, 90 ohms.
2. By the fault, 20 ohms.

Their joint resistance $\frac{90 \times 20}{90 + 20} = 16$ ohms, nearly.

Add battery . . . . . 10 „

The total resistance will be only 26 ohms.

Current leaving battery $\frac{1{,}000}{26} = 38$.

The two circuits beyond the fault are in the proportion of 2 to 9, and $\frac{38 \times 2}{11} = 6{\cdot}9$, will be the strength of the signals, instead of 10.

Fourth case. The fault 20 ohms from A.

$60 + 10 = 70$ ohms, line and instrument,

20 ohms fault,

are the two circuits between which the current will divide, and $\frac{70 \times 20}{70 + 20} = 15{\cdot}5$ their joint resistance.

Entire resistance of circuit:

Battery	10	ohms.
Wire to fault	20	„
Beyond fault	15·5	„
Total	45·5	ohms.

Current leaving battery $\frac{1,000}{45{\cdot}5} = 21{\cdot}7$ nearly, and $\frac{21{\cdot}7 \times 2}{9} = 4{\cdot}8$ nearly, the strength of signals.

Fifth case. The fault 20 ohms from B, its resistance 20 ohms.

$20 + 10$ ohms, line and instrument.

$\frac{20 \times 30}{20 + 30} = 12$ joint resistance.

Total resistance:

Battery	10	ohms.
Wire to fault	60	„
Beyond fault	12	„
Total	82	ohms.

The current leaving the battery $\frac{1,000}{82} = 12{\cdot}2$ nearly, and $\frac{12{\cdot}2 \times 2}{5} = 4{\cdot}8$ nearly, the strength of signals.

Thus, on a circuit consisting of:

Line wire of	80	ohms' resistance;
Instrument	10	„
Battery	10	„

with an electromotive force of 1,000,

The strength of signals, when the line is perfect, will be 10·0 parts.
When a fault of 20 ohms' resistance is in the centre 4·4 „
The same fault 20 ohms from receiving station . . 4·8 „
„ „ 20 ohms from sending station . . . 4·8 „
„ „ at the receiving station . . . . . 6·9 „
„ „ at the sending station . . . . . 6·9 „

Thus, the effect of a fault is greatest when in the centre of such a line.

220. The following formula, from Gavarret's excellent work on the telegraph, will be found more convenient for these calculations. It gives the effective current, or the strength of the signals :—

1. Call the resistance of the line between the sending station and the fault, including the battery and apparatus, R.
2. Call the resistance of the line beyond the fault, including the receiving apparatus, r.
3. And the resistance of the fault itself, f.
4. Let the electromotive force of the battery be E.
5. Multiply R by r.
   Multiply R by f.
   Multiply r by f.
   Add the three products together.
   Multiply f by E, divide this product by the sum of the three previous products, the quotient will be the strength of the signal at the receiving station.

Expressed algebraically, the formula reads thus :—

$$\frac{E\,f}{R\,r + R\,f + r\,f} = \text{strength of signals.}$$

The first case will be calculated thus :

$R = 50.\quad r = 50.\quad f = 20.\quad E = 1{,}000.$

$50 \times 50 = 2{,}500$
$50 \times 20 = 1{,}000$
$50 \times 20 = 1{,}000$
$4{,}500$

and $20 \times 1{,}000 = 20{,}000$, which divided by 4,500 gives 4·4 as the strength of the received signals.

In the fourth case, R = 30, r = 70, f = 20, E = 1,000.

$$\frac{1{,}000 \times 20}{30 \times 70 + 30 \times 20 + 70 \times 20} = 4{\cdot}8.$$

In the fifth case, R = 70, r = 30, f = 20, E = 1,000.

$$\frac{1{,}000 \times 20}{70 \times 30 + 70 \times 20 + 30 \times 20} = 4{\cdot}8.$$

221. It will be seen that the values of R and r in the two last calculations are transposed. Thus, when the resistance of the battery is equal to that of the receiving instrument, a fault arising at a given distance from the sending end of the line will have an effect on the signals equal to that of the same fault at an equal distance from the receiving end.

Both stations will be equally affected by it.

But, practically, as the battery of a long circuit consists of many cells, it offers much more resistance than the instrument, and therefore the centre of the *line* will not be the centre of the *circuit*, which comprises not only the line wire, but the battery and instrument. The effect of a fault on signals will therefore be greatest when nearest the *sending* station, thus:

222. Take a case in which an earth of 10 ohms' resistance occurs 5 ohms from A, and 115 ohms from B (Fig. 51): the re-

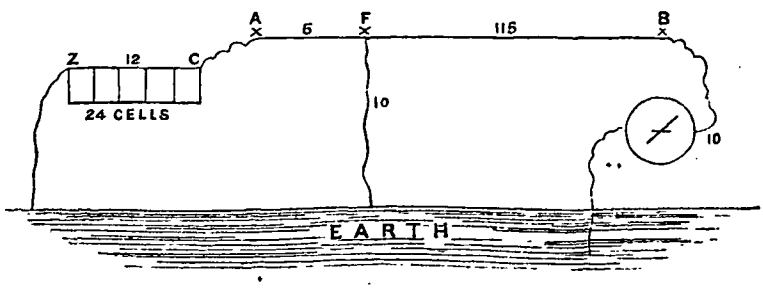


FIG. 51.

sistance of the instrument or galvanometer being 10 ohms, of the battery of 24 cells 12 ohms, and the electromotive force 10,000.

When A sends a signal from 24 cells,

$$E = 10{,}000,\ R = 17,\ r = 125,\ f = 10,$$

the effective current received at B will be

$$\frac{10{,}000 \times 10}{17 \times 125 + 17 \times 10 + 125 \times 10} = 28.$$

When B sends,

$$E = 10{,}000,\ R = 127,\ r = 15,\ f = 10.$$

Effective current received at A,

$$\frac{10{,}000 \times 10}{127 \times 15 + 127 \times 10 + 15 \times 10} = 30.$$

Now calculate the effect of increased battery power, say 48 cells.

A sending:—

E will be doubled = 20,000; the battery resistance is also doubled.

R = battery 24 + line 5 = 29.
r = instrument 10 + line 115 = 125.
f = as before . . . . . = 10.

Effective current, $\frac{20{,}000 \times 10}{29 \times 125 + 29 \times 10 + 125 \times 10} = 38.$

B sending:—

E = 20,000.
R = battery 24 + line 115 = 139.
r = instrument 10 + line 5 = 15.
f = fault . . . . . = 10.

Effective current, $\frac{20{,}000 \times 10}{139 \times 15 + 139 \times 10 + 15 \times 10} = 55.$

Here, as the resistance of the battery increases, the difference in the effect of the fault on signals received at the two stations increases also.

Double the size of the plates, halving the resistance.

A sending:—

E = 20,000.
R = line 5 + battery 12 = 17.
r = line 115 + instrument 10 = 125.
f . . . . . = 10.

The effective force is 56.

B sending:—

E = 20,000.
R = line 115 + battery 12 = 127.
r = line 5 + instrument 10 = 15.
f . . . . . = 10.

The effective current is 60.

Here the effective current is just double that of 24 cells of the smaller size. The battery resistance having been halved, the total resistance is the same as with 24 cells, while the electromotive force is doubled.

223. To sum up the foregoing calculations and extend them in a tabular form:—

If on a wire, whose resistance is 120 ohms, there be a fault offering a resistance of 10 ohms, situated 5 ohms from the end A; then, if the recording apparatus have a resistance of 10 ohms, the battery of ½ ohm per cell, and if the electromotive force (E) be 10,000 per trough of 24 cells—the effect of the fault on the current received at each terminal station is as follows:—

No. of cells.	Resistance of Battery, in ohms.	E.	Strength of Signals received at A near the fault.	Strength of Signals received at B distant from the fault.
24 small	12	10,000	30	23
48 ,,	24	20,000	55	38
96 ,,	48	40,000	94	47
192 ,,	96	80,000	147	53
24 double	6	10,000	31	36
48 ,,	12	20,000	60	56
48 treble	8	20,000	61	66[1]
96 double	24	40,000	110	77

[1] This case is an exception to the general rule that the signals received at the station farthest from the fault are more enfeebled than those received at the

The current received from 24 cells, when the line is perfect, is 70, and from 48 cells 130.

In France, where the resistance of the coil is extremely high, the station *nearest* a fault is most affected by it; hence their works on practical telegraphy appear to contradict what has just been stated.

224. When there are several faults the calculation is much more difficult; with two faults the law is this:

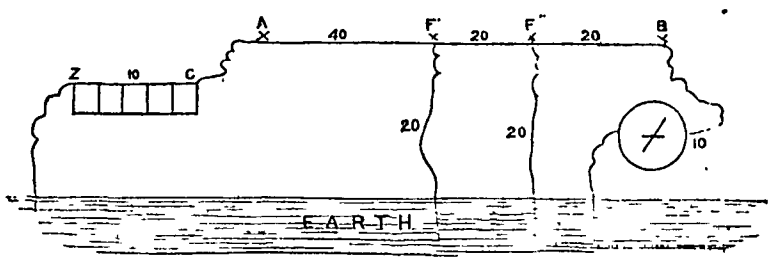


Fig. 52.

Taking the same circuit, as in the former cases, with two faults, F′ and F″, each of 20 ohms' resistance, the first 40 ohms from A, the second 20 ohms from B.

When the line is perfect the resistance will be 100, and the current $\frac{1,000}{100} = 10$, as before.

With one fault at F′ the resistance $\frac{50 \times 20}{50 + 20} = 14{\cdot}2 + 50 = 64{\cdot}2$.

With one fault at F″ ,, $\frac{30 \times 20}{30 + 20} = 12 \quad + 70 = 82{\cdot}0$.

With both faults,

Resistance beyond F″. . . . = 12 ohms.
,, between F′ and F″ . = 20 ,,
Total resistance beyond F′ . . 32 ohms.

station nearest it. The reason is, that in this case only is the resistance of the battery less than that of the coil of the apparatus.

The joint resistance of F′ and the circuits beyond it are

$$\frac{32 \times 20}{32 + 20} = \frac{640}{52} = 12{\cdot}3$$

Add the battery and the line from A to F′ 50·0

Total new resistance 62·3 ohms.

Current leaving the battery $\frac{1{,}000}{62{\cdot}3}$ = 16 parts instead of 10.

This current will divide at F′ between the wire and the fault, in the inverse proportion of the resistances 20 and 32, and 6·1 parts will go towards B; this will split again at F″ between the two resistances 20 and 30, and 2·4 parts will reach the receiving apparatus.

225. Occasionally, when insulation is very defective, a wire will test alike whether disconnected at the distant end or not, yet sufficient current will reach the instrument to give readable signals.

Take a circuit of 40 ohms, and let there be a fault of two ohms' resistance in its centre,

$\frac{20 \times 2}{20 + 2} = \frac{40}{22} = 1{\cdot}8$ will be the resistance beyond the fault.

Force of battery . . $\frac{1{,}000}{\text{Resistance of circuit } 1{\cdot}8 + 20} = 45{\cdot}8$, the current passing out to line.

$\frac{45{\cdot}8 \times 2}{22} = 4{\cdot}1$, current reaching the instrument.

If the wire be disconnected at B, the total resistance of the circuit will be 22 ohms instead of 21·8, and the current passing out to line 45·4, instead of 45·8, or almost exactly the same as when not disconnected.

226. The laws of *derived currents*, or faults, as already explained, will enable us to calculate the effect of connecting instruments, so as to divide a current between them, thus :—

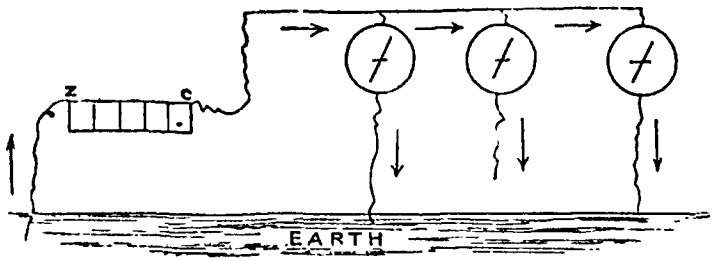


FIG. 53.

227. The same law will enable us to explain how it is that there is no appreciable difference in the signals, whether the needles of a double-needle instrument are worked singly or together, although the effect of working both at once is precisely the same as establishing an earth of equal resistance to the entire circuit excepting the battery, close to the sending station.

Take the line of 70 ohms, with battery and instruments each of 10 ohms' resistance, and force of battery 1,000.

When one needle only is used, $\frac{1,000}{100} = 10$ will be the signal.

When both are used, the current will divide thus :—

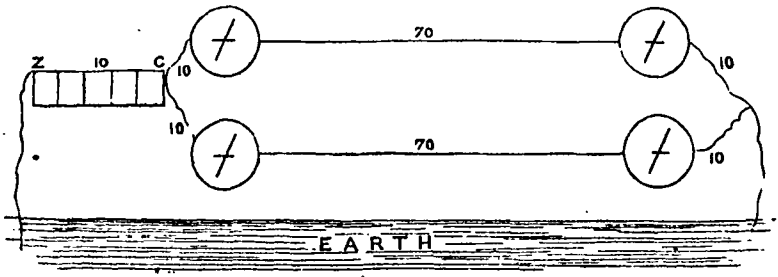


FIG. 54.

And we have $\frac{90 \times 90}{90 + 90} = 45$ ohms as the joint resistance of the two wires.

Adding the battery 10 ohms, $\frac{1,000}{55} = 18$ will be the current passing out to line, and 9 the signal instead of 10. If the battery had less resistance, the difference of signal would be

less; and if it were nothing, the signal would not be affected at all. But the battery, being harder worked, would get weak much more quickly.

228. Thus, two or more wires of similar resistance, if of considerable length, can be worked from the same large battery, provided they be well insulated, and that the current be sent on each in the same direction; for if the copper be put to earth on one circuit, while the zinc is to earth on another, the battery will be on "short circuit." Double sets of batteries, one for the positive and the other for the negative current, allow of reversals.

A great objection to the method is, that a battery fault affects all the circuits connected with it, and a line fault renders the current very variable, as may readily be seen on a double-needle circuit. The system has, however, been extensively employed on the Continent, and is universal in the United States.

At the central office in Amsterdam, where single (unreversed) currents are used, the battery consists of zinc-carbon and dilute sulphuric acid. The terminal zinc is put to earth, and the instrument wires of the shortest circuits are connected to the 20th carbon, so that they are worked with a tension of 20 cells: others are connected at the 40th, 50th, and 80th, and the longest circuits at the 100th or terminal carbon.

From the 100th to the 81st, inclusive, the cells are arranged in single series; from the 80th to the 51st three series are placed side by side; four series from the 50th to the 41st; from the 40th to the 21st there are five sets side by side, and the 20 nearest the zinc end, which are used in the shortest lines, consist of six series.

The local battery is 45 similar cells arranged in 3 series of 15 cells side by side.

From these batteries forty circuits are worked, and, it is said, with success.

In the United States a single series of Grove or Bunsen batteries are used for all the circuits, and it is stated by one of

the leading American electricians that it was found on a very wet day, if a circuit of 100 miles was connected to 60 cells of Bunsen, the addition of three similar wires reduced the current on the first one 12 per cent. He adds, that it is a common practice to attach as many as eight wires to such a battery, which in the case named would have reduced the current about 25 per cent.

He also states that, in the opinion of many of those best qualified to judge, it would be more economical and more efficacious to use a separate set of Daniell for each circuit.

229. The law that a current *splits* or divides according to the resistances of the several paths open to it, enables us to explain a method which has been proposed for signalling across rivers without wires.

Large copper plates are placed in the water at A, B, E and D

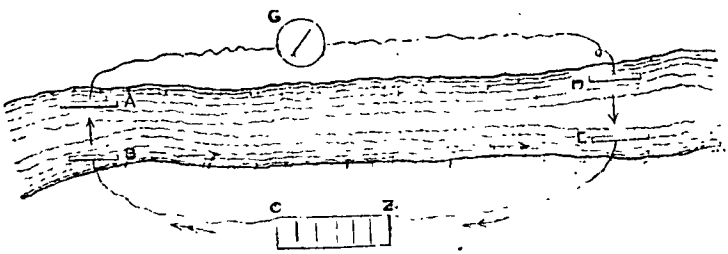


FIG. 55.

(Fig. 55), connected by insulated wires. Two paths are then open to the current from the battery C Z; C B E Z following the course of the river-bank, and C B A G D E Z crossing the stream, passing through the wire A D and the galvanometer G. In order that sufficient current to produce a signal shall pass through G, it is necessary that the distance B E along the bank should be considerably greater than double the breadth of the river. We are not aware that this method has been adopted in practice.

The same explanation applies to the singular case, which occasionally occurs, in which signals pass through a broken wire, the ends of which lie on the ground at a short distance from each other.

230. The foregoing calculations show that increasing the size of the plates, rather than increasing their number beyond a certain limit, is theoretically the best method of providing for the loss of current arising from defects in insulation. Practice fully confirms the theory.

231. There are other reasons against increasing the number of cells of a battery when the line resistance is lessened by bad insulation. It exhausts the battery very much more quickly, because of the increased action due to increased electromotive force, and it is much less economical.

Besides this, the diminished resistance of the line decreases the tension of the battery, reducing its *working power* below that of a smaller number of larger cells.

To give examples: Mr. Varley records the following observations made on the London-Bristol circuit, at a time when the insulation was far less perfect than at present, and when sand batteries were used, which are much more quickly exhausted than the batteries now employed.

The number of cells usually employed was seventy-two, the plates measuring three inches by four. On a very wet day Bristol was unable to read. The batteries were tested for resistance with a thick wire detector (quantity detector), and gave 40° on short circuit. The signals were not legible until the number of cells had been quadrupled. After an hour they again failed. The batteries now showed but 25°, instead of 40°, having nearly doubled in resistance; and when tested for tension, by placing a galvanometer in circuit with the line, indicated 14° as the strength of the current flowing from battery to line.

The 288 cells were then formed into two series of 144 cells each, the copper poles of each set being connected to the copper terminal of the instrument and the two zinc poles to the zinc terminal of the instrument. The battery thus arranged was equivalent to 144 cells of double the usual surface. When this

was joined to the line, the electricity leaving the battery indicated 20°. Bristol now read well. When the battery was again joined up in one series of 288 cells, Bristol could not read.

It is evident that the tension of the current, leaving London, was greater from 144 large cells than from 288 of half the size.

Again: the signals upon the same circuit having failed on a wet day, 144 cells were added for *tension*, and communication was restored. But after two hours the signals again failed, and when the original seventy-two cells were tested for resistance, they gave 3° only. Upon removing them from the series, leaving the 144 cells which had been added, Bristol read well. Thus, the increasing the electromotive force of the series completely exhausted the defective set.

The following results were obtained by Mr. C. V. Walker, in actual experiment, on a very bad line of 5½ miles, including a defective tunnel. The current received at the distant end was: —

From	24	cells,	ordinary size	10
„	24	„	double „	24
„	24	„	treble „	27
„	24	„	four-fold „	30
„	24	„	five-fold „	31
„	24	„	six-fold „	32
„	48	„	ordinary „	19
„	48	„	double „	37
„	48	„	treble „	46
„	72	„	ordinary „	21
„	72	„	double „	43
„	96	„	ordinary „	23
„	120	„	ordinary „	26

232. The chemical action, in each cell of a series, is precisely equal and proportional to the current produced (59). It is evident, therefore, that if we can obtain the same effect by a

certain number of large cells as by twice the number one-half the size, the consumption of zinc and sulphate of copper will be reduced one-half.

233. However well a line may be insulated, there is an enormous difference between wet and dry weather; the insulation of the best lines falls very low (comparatively speaking) in heavy rain.

The average insulation resistance per mile of a circuit of 280 miles of No. 4 wire was found to be

	Ohms.
In moderately fine weather	13,700,000
Lowest insulation in wet weather while working well	192,000
Insulation at which communication became difficult	182,000
Resistance of the wire itself	2,260

It may be that the 280 miles of wire would work with an average insulation of 182,000, if the leakage were uniformly distributed; that is, if one part of the line were as good as another. Such a condition is, however, never attained in practice, and, as will easily be understood, there is a great difficulty, when communication is slow and business delayed, in learning precisely the condition of each portion of the line. In the case of a somewhat shorter and better insulated line the highest recorded insulation per mile was—

	Ohms.
In fine weather	78,750,000
The lowest in wet weather while working well . .	131,000
The circuit was not stopped at	91,900

This last circuit is never seriously affected by weather: the insulation never falls below the working point, unless in case of accident; and, generally speaking, no circuit, insulated with the double brown ware, not exceeding 400 miles, even if not of larger gauge than No. 8, is ever stopped by this cause except it run for a considerable distance near the sea; and not even when near the sea unless some of the insulators are cracked.

PART VII.

THE CONSTRUCTION OF A LINE OF TELEGRAPH.

234. In order to establish communication between two places it is necessary to erect a wire of sufficient conductibility, and to insulate it sufficiently well. A good earth connection must be provided at the terminal stations, and a circuit formed, including the earth, the apparatus, the line wire, the apparatus at the distant station, and the earth again. Intermediate stations are introduced by cutting the wire, and placing the instrument between the divided ends.

235. Leaving first cost out of consideration, it is better to use suspended rather than buried wires, because of the liability of gutta-percha and india-rubber to deteriorate, and the expense of repairing faults. It is better to use iron wires carried on poles over tunnels, than covered wire through them. In towns, however, if there are many wires, it is better to carry them under the streets than over the houses.

236. Short lengths of covered wire should be avoided as much as possible.

237. The preparation of percha and rubber, and especially the method of joining several pieces, have been so greatly improved since the failure of the extensive systems of buried wires in Prussia and in England, that long subterranean lines are now quite practicable, where special circumstances make them necessary.

238. No instance has occurred of percha having deteriorated

when placed under water. In the sea it appears to be indestructible. There is no experience at present as to the permanence of rubber under water. Hooper's material appears to be permanent.

239. The best foreign timber is the most durable; but its price precludes its use in England, except where a more sightly appearance or extra strength is required. English larch, from thirty to forty years' growth, cut close to the ground so as to obtain the "natural butt" of the tree, having its rings close and containing a fair proportion of heart wood, if felled in the winter and well seasoned, is very suitable; but, if possible, the poles should be prepared with some antiseptic, such as creosote, or sulphate of copper. The poles, if unprepared, should be barked and stacked in such a manner as to allow a free circulation of air among them, the lowest tier being raised several inches from the ground. They should be protected from the sun, so as not to dry too quickly, or they will split.

If the bark is allowed to remain on, splitting will be prevented, but they will be liable to be attacked by boring worms and other insects; and the sap, when prevented from drying out quickly, ferments, and forms the germs of decay.

The butt ends should be well *roasted* over a slow fire. From the bottom to a foot above the intended ground line should be slightly charred, and tarred, when hot, with a mixture of four parts of gas tar (boiled with powdered *quick* lime, to expel the water and ammonia) and one of Stockholm tar. When set on the line, they should be allowed to remain for three or four months to dry thoroughly, before they are painted, which should not be done except in dry weather.

If it be impossible to procure seasoned timber, the butts should be charred and baked, *but not tarred;* for coating green timber prevents its dying, and causes it to decay. When the timber has become well seasoned, the soil may be removed to a depth of at least a foot around the bottoms of the poles; and

when this part has become dry, the tarring and painting may be proceeded with.

It is difficult to creosote larch unless it is perfectly dry. Round Baltic poles creosoted are suitable, but unless prepared they will not last so long as seasoned larch.

For lines of ten wires, or less, a diameter of five inches at top is sufficient; if more than ten wires, six inches. The greater the distance from one another at which the poles are set, the stronger must be the timber.

240. On railways, so far as possible, the wires must be placed within sight from the trains, so that they may be readily inspected. Bearing this in mind, the poles should be set at the greatest possible distance from the metals, so that if a pole be broken it shall fall clear of the line. The holes should not be less than five feet deep.

241. When poles fall across the rails the platelayers are compelled to cut the wires to clear the line, so that they *run back* a considerable distance, increasing the damage six-fold. The same occurs when the wires fall across a public road. It is better, therefore, on very important circuits, that they be *terminated* at each end of large station-yards, where the poles cannot be placed free from the lines of rails; so that if an accident occur, and the wires be cut by the workmen, they may not run back beyond the terminal poles.

242. Too much care cannot be taken when the wires cross a public road, especially when they pass over a bridge by which the road crosses the railway. It is better in turnpike roads to place a pole on each side of the bridge, and to double bind and solder the wires to the insulators at these poles, and double bind, without soldering, at three or four poles on each side; so that the breaking of a wire near the spot shall not, by any chance, cause it to drop so low across the road as to endanger the traffic. Each wire should be *guarded*, to provide against danger from broken insulators.

However desirable it may be to set poles in a straight line upon railways, it is objectionable doing so on roads when they must be crossed either wholly, or partially, by the wire. Roads should never be crossed by the wire unless imperatively necessary. Every such crossing is an indefinite source of risk to persons travelling on the road either in snow-storms, frosts, or gales.

243. Over tunnels or bridges, in places which are not within sight, or where there would be more than ordinary difficulty in executing repairs, the work should be unusually strong, the best wire used, the greater distance given between wire and wire, so as to make such portions less liable to interruption. In such places, it is also desirable to use iron hoods to protect the insulators from damage by stones, and to fix guards to catch the wires, should they become detached by the breaking of the insulators or bindings. On curves, also, the wires should be guarded, especially so on the inside of the curve.

244. The smaller the number of poles to the mile, the better will be the insulation, and the less the cost; but the greater the liability to accident, and the greater the difficulty of making repairs.

Experience has shown, that for a telegraph of more than about eight wires, there should not be less than twenty poles to the mile on straight parts of the line, and a greater number on curves, dependent on the radius (or sharpness) of the curve, and on the direction of the strain. When the poles are set on the outside of the curve, the strain tends to pull them towards the rails, and if a wire break loose, it will hang nearer the trains than it did when in its place; so that there is a greater chance of accident to the train than when the poles are on the *inside* of the curve, and would fall from the metals. On branch lines, where not more than four wires will be required, sixteen poles per mile, or even fewer, are sufficient, provided they can be set so far back that if they fall they shall clear the rails.

It is better, if possible, to allow the earth time to consolidate round the poles before the wires are fixed, that their strain may not pull the poles out of place.

245. The pressure of the wind on the poles and wires is *very great* in a gale; it is, therefore, desirable to erect the telegraph on the *lee side* of the railway, where it may be sheltered from the prevailing winds. Where the line runs north and south the east side should always be chosen. In cuttings, where the wires are sheltered, although the poles are necessarily set near the rails, the risk is much less than on embankments, where the wires are fully exposed, and where a side wind will blow them across the line, sometimes even to a distance equal to their dip or "*sag*." When the span is long, and the wires consequently slack, the distance from the rails must therefore be correspondingly greater.

246. The poles must always be made to lean back slightly against the strain of the curves, and should be stayed so as to oppose the strain. On straight lines and slight curves, where exposed to the wind, double stays, to prevent their moving either way, are required; for if one stay only is used, the poles will spring back during the lulls of a gale blowing from the side opposite to the stays, and the wires will not only be made to swing into contact, but the stay will be loosened, or even broken. On sharp curves the strain of the wire acts as a stay in one direction. Each pole must be made as stiff as possible in order to be perfectly secure. The earth must be well rammed, especially at the top and bottom of the hole; and if stones can be obtained, they may be so placed as to give the pole a firm thrust against the undisturbed part of the soil.

A peculiar tool is used in Spain for digging holes. A segment of a disc (about one-sixth) is fixed on the end of a staff six or seven feet long, and at right angles to it; the disc has a ledge or rim on one side and at the end. If this tool is pressed against loose earth and turned a quarter round, it takes up a

portion which the ledge prevents from falling off. To dig a hole two men are employed, one with the tool, the other with a crowbar to loosen the earth. By this method no more earth is removed than is just enough to receive the pole, and it is, in consequence, more firmly fixed than by the ordinary method. It succeeds very well in alluvial soil, gravel, or even in clay, but not at all in peaty or sandy soil. It can be used in a hole filled with water.

247. However well rammed, stays are apt to draw and become loose in light soil. When large stones cannot be found, an iron stay anchor, or a piece of an old pole, sound and well charred, can be used. And in all cases, most especially in sand, the hole should be *undercut*, so that the stone or log may have a pull against the solid undisturbed earth.

Wire stays are apt to rust at the surface of the ground, and should therefore be well tarred or painted; an iron rod, projecting a foot or two above the soil, to which a wire can be fastened, is to be preferred. A few links of chain may be attached to the stay wire, and the rod may terminate in a hook; this is an easy method of tightening the stay. For terminal poles, or poles having great strains, rods, not twisted wire, should always be used. It is very difficult to make a stay of several wires, whether twisted or not, in such a manner as to distribute the strain equally between all the wires of which it is composed; and as twisted wires expose a larger surface than rods, they rust more quickly.

248. When a stay is fixed to the top of a pole on which there is much strain, the pole bends below the stay; if the stay is fixed below the wire, the pole bends above. In such cases the stay should consist of two branches, one fixed above and the other below the wires, uniting into one a few feet below the lowest wire.

249. Poles exposed to a great strain may with advantage be "trussed" like a girder. The strain with a rod or twisted wire

tends to render the opposite side of the pole convex, but the pole cannot bend without stretching the truss wire. It should always be fixed round the bottom of the pole, for if fixed at the ground line it will give it a tendency to break off at that point.

250. In soft soil, and generally where great strength is required, struts are to be preferred to stays, as they compress instead of lifting the earth, which, after long-continued rain, becomes very soft and yielding; but whenever a strut is used, it must be remembered that the strain of the wire tends to bend the pole below the strut—the point of the latter acting as a "purchase" or fulcrum; and again, that the strut itself is liable to bend. These inconveniences are met by tying or framing the two together.

The strain of the wires on a terminal post tends to push the strut into the ground. A flat stone, or piece of timber, should therefore be placed under the foot of the strut, to give it an enlarged bearing. The strain will also tend to turn the pole upon the fulcrum formed by the upper extremity of the strut, so as to lift the heel of the pole out of the ground. A sleeper or log, well backed up with large stones, should therefore be so placed as to give the pole a solid thrust against the firm soil.

251. Where neither stays nor struts can be fixed, two poles may be set side by side and bolted together; or they may be arranged as the letter A, a broad bearing against the soil being given by sleepers laid horizontally.

When a large number of wires are required, they are carried on two sets of poles framed together so as to support one another. There is, however, nothing special in these methods of construction which will not be obvious to any skilled workman.

252. In deciding on the strength of a line, it must not be forgotten that on very rare occasions, when the air near the ground is rather colder than above, and when snow falls at a temperature a little above freezing, it adheres to the wires, and,

if the downfall continue, will coat them to a sufficient thickness to break them and the poles. It would seem that no *practicable* strength of construction will enable a line to resist the combined effect of a coating of snow followed by a gale. In Holland the mists freeze upon the wires, giving them a coating of several inches diameter, which splits when the sun breaks out, forming, as it were, splinters, which interlace and connect the whole of the wires.

Where there are heavy falls of snow, sufficient room must be left between the insulator and pole to prevent the snow lodging there, and the supports should be specially arranged with the same object.

253. Each pole should be furnished with an *earth wire*, or contact conductor (212), which should be put on the pole before it is fixed, and be formed into a flat coil attached to the foot of the pole, so as to expose as large a surface as possible to the earth.

It is very important this wire should make good earth. When this cannot be effected, the conductor should be dispensed with.

254. WIRE.—For ordinary purposes, galvanized iron wire of No. 8 gauge, 0·170 inch diameter, is used; for short lines, No. 11, 0·125 inch diameter; and for long important circuits, No. 4, 0·240 inch diameter. These gauges are very nearly the same as those employed in France,—4, 3, and 5 millimetres.

255. The smaller the wire, the more care is needed in insulation, for an increased resistance in the wire virtually adds to the length of the circuit. It has been found that with wires equal in insulation, a circuit which *works badly* with a No. 8 will *work well* with a No. 4 line-wire. No. 11 wire rusts away very quickly in smoky places; it is sometimes worn through by chafing at insulators, and is apt to stretch at the points of support if the spans are too long.

256. Wire, for general use, should be soft, and capable of stretching 18 to 20 per cent. before breaking. For *very* long

spans, harder wire, which does not stretch so readily, is preferred. The soft wire should be capable of being bent at right angles several times backward and forward without breaking, so that joints may be made securely, and the breaking strain should not be lower, for No. 8, than 1,300 lbs. In France annealed charcoal wire is used; the No. 8 is required to stand a *sudden* strain of 968 lbs. (440 kilos.), and the No. 11, 550 lbs. (250 kilos.). It must bear bending at right angles in a vice, first one way then the other, four times; and must stand wrapping round itself. Charcoal wire is of a better quality and more expensive than the wire generally used in England.

257. Common wire is made in somewhat short lengths, which are welded together. The welds are very often defective: weak places are also caused by dirt or cinder in the iron, and by splits in the rod, and it is most desirable to find out and remove these causes of accident beforehand; for when wires are broken by contraction in frosty weather, or by a gale, the failures *always* occur at these weak places, or where the wire has been chafed by an insulator. The wire should therefore be strained till it stretches after it is laid out on line, which will break it if defective. This process will also remove the wrinkles and irregularities, and not only makes the wire look much better, but renders it less liable to be set swinging by the wind, and, should it be put in motion, less liable to catch and remain in contact. If a straining machine is not at hand, let it be drawn as tight as possible by ropes and blocks, and then pulled at the centre of its length across the line till it stretches. It will be found to have lost its spring, and can be so easily handled that it is technically said to be *killed*.

Great attention is now paid to the manufacture of telegraph wire. The best quality is now drawn in lengths weighing 80 or even 120 lbs., *without welds*, and is *killed* or stretched about 2 per cent. by the manufacturers, by passing over two drums,

one of which is slightly larger than the other. It is also made to pass under and over pulleys arranged in a zigzag form, in order to open and break any *splits* that may exist.

The longer a bundle of wire is, the better, provided it does not exceed a weight which is convenient to handle, 112 to 120 lbs.; because it is desirable to have as few *joints* as possible, as they are apt to cause *contacts.*

When the wind is high the wires are blown together, and if there be no joint, or other inequality, by which one may catch and cling to the other, they fall apart again; but where there are joints they hook themselves together, and remain in contact until the line-man separates them.

It is, in fact, desirable never to make a joint except within ten feet of a pole, where the wires cannot blow into contact.

Permanent contact is sometimes caused by the clinging together of slight bends and irregularities which occur in unstretched wire: these are removed by the killing; and, indeed, it seems that killed wire is scarcely acted upon by the wind, for it may be seen comparatively still when others on the same poles, which retain their irregularities, are swinging to and fro.

258. The results of tests, for *breaking strain,* vary very much with the method in which the test is made.

In comparing various kinds of wire, the tests should therefore all be made by the same method.

The usual method of finding the breaking strain is to place a piece ten inches long in a testing machine, either worked as an hydraulic press or by screws. By adopting a length of ten inches, the calculation of the percentage of strain and elongation is rendered very easy. Such a machine acts rapidly; it does not give the wire time to break before a greater strain has been put upon it, and, consequently, its indications are often too low. A sample of ten inches of good No. 8 iron wire, tested by the hydraulic machine, will break at about 1,300 lbs. A yard of the same wire will break at 1,100 lbs. if tested by a

scale and weights, allowing it time to stretch after each addition of weight. But if the weights are put on quickly, the conditions will be nearer those of the testing machine, and it will, apparently, bear a heavier strain. And if the weights are thrown into the scale so as to jerk the wire, it will break more readily.

Again, if we test a length of eighty-eight yards, the distance from pole to pole where there are twenty to the mile, the wire will not bear more than 1,000 lbs. Thus, a wire which in the hydraulic machine bears 1,300 lbs., will only bear 1,000 lbs. in actual practice.

When a piece of wire is clipped between two vices for testing, the sharp edges of their jaws must be rounded off, or they will cut the wire and cause it to break close to the vice. If the wire is fastened to a hook instead of to a vice, it must clip the hook closely; and if a loop or fastening is made by twisting, it will certainly break—it should be bound like a Britannia joint.

The percentage of elongation before breaking is affected in precisely the same way; a wire will stretch more if the strain is put on quickly, than it will if it is allowed to complete the elongation due to each successive increase of weight before the weight is increased.

The following are the means and extremes of 27 different samples tested in 10-in. lengths by the *hydraulic apparatus*:—

No. 8 Gauge.	Means.	Extremes.
Diameter before testing	0·151 in.	0·147 to 0·153 in.
,, after having been broken . .	0·140 in.	0·136 to 0·144 in.
Percentage of stretch before breaking . .	20	19 to 25
[1] Strain required to stretch the wire . . .	672 lbs.	600 to 750 lbs.
Breaking strain	1318 lbs.	1250 to 1440 lbs.

[1] It seems to be difficult to ascertain the precise moment at which elongation commences.

No. 11 Gauge.	Means.	Extremes.
Diameter before testing	0·115 in.	0·112 to 0·120 in.
,, after having been broken. . .	0·106 in.	0·100 to 0·117 in.
Percentage of stretch before breaking .	20	19 to 25
Strain required to stretch the wire . . .	505 lbs.	400 to 600 lbs.
Breaking strain	776 lbs.	740 to 850 lbs.

The following are means of ten tests of wire of the same quality and from the same makers, tested in lengths of 33½ inches by *scale and weight*, adding 56 lbs. at a time, gently and without jerk, and waiting until the wire had ceased to stretch before adding more weight:—

Percentage of stretch before breaking	11·2
Strain required to stretch the wire	904 lbs.
Breaking strain	1,132 lbs.

The following trials show the effects of annealing and of galvanizing:—

No. 8 Iron.	Mean Breaking Strain.	Mean percentage of Stretch before Breaking.
No. 1 *Sample.*		
Before galvanizing	1,138 lbs.	18·75
After ,, ...	1,169 lbs.	12·88
No. 2 *Sample.*		
Before galvanizing	1,090 lbs.	19·39
After ,, ...	1,194 lbs.	13·09
No. 3 *Sample.*		
Before galvanizing	1,107 lbs.	20·66
After ,, ...	1,125 lbs.	17·58

Homogeneous Iron, Nos. 11 and 12.	Breaking Strain.		Percentage of Stretch.	
	Means.	Extremes.	Means.	Extremes.
Before annealing .	910 lbs.	830 to 1060 lbs.	·92	0·75 to 1·25
After ,, .	612 lbs.	560 to 700 lbs.	20·05	17·00 to 21·50
Before galvanizing	612 lbs.	560 to 700 lbs.	20·05	17·00 to 21·50
After ,, .	634 lbs.	560 to 700 lbs.	11·64	9·00 to 15·00

The results of a large number of tests by the hydraulic machine of the best quality of telegraph wire in the year 1870, are, for average elongation,—No. 4, 17 per cent.; No. 8, 19 per cent.; No. 11, 20 per cent. The tests were made upon 10-inch lengths.

259. Galvanized[1] wire must always be used for permanent work, no system of painting or varnishing the iron itself having been found to answer as well.

260. The French test the thickness of the zinc coating by dipping the wire in a solution of sulphate of copper. The process is this:—Dissolve one pound of sulphate of copper in five pounds of water; plunge the wire into the solution; let it remain one minute, and then wipe it clean; repeat this process four times. If the wire appears black after the fourth immersion, it shows that the zinc has not been all removed, and that the galvanizing was well performed; but if it has a copper colour the iron has been exposed, proving that the zinc was too thin. The reason is that the acid of the sulphate leaves the copper for the zinc, dissolves it, and leaves a black deposit of copper upon the wire; but when the zinc has been entirely

[1] Galvanizing simply means coating with zinc. The term is apt to mislead, and it would be far better to use the word "zincing," as we call coating with tin, by an analogous process, tinning.

dissolved away and the copper is deposited on the *iron*, it bears its natural hue just as when a knife is dipped into sulphate of copper.

Galvanizing does not seem materially to alter the breaking strain, but it has a decided effect upon its capacity of stretching by slightly hardening the metal.

261. The zinc coating appears little the worse after twenty years' use, except in towns, in the vicinity of the sea, and where it is exposed to the steam and smoke from locomotives, as in tunnels, deep cuttings, and stations. In some places, No. 8 wire will not last more than four years. So rapid is the corrosion in manufacturing towns, that it is useless employing a smaller size than No. 8 gauge, unless it be specially protected.

Paint, or even gas tar, protects galvanized wire where it adheres, but it cannot be applied in the manufactory so as not to be liable to be rubbed off here and there; and as no chain is stronger than its weakest point, so a wire which has rusted in spots where the paint has failed, might almost, if not quite as well, not have been painted at all.

It is a most expensive and tedious process to paint after the wire has been fixed, but it is easily done where the wire can be stretched along the lower part of the poles so as to be reached from the ground. Even if the work is done well, the paint is apt to be removed at the points of support, leaving the wire unprotected just at the very point where its full strength is most needed. Moreover, metal can only be effectually painted in dry weather when it is perfectly free from damp, and it is almost impossible to secure sufficient care in this respect from the workmen. The only plan which has really succeeded is that of running the wire through a paint or bituminous preparation, and immediately spinning around it cotton tape well saturated with the same compound. The tape protects the coat of paint from abrasion, and, at the same time, causes it to adhere to the wire.

It is perfectly useless to attempt to stay the progress of rust after it has once commenced; for however carefully the wire may be cleaned, the rust forms again under the paint and thrusts it off. If a speck of rust is seen on the tubes of the Britannia Bridge at Bangor, it is carefully chipped off with a cold chisel before it is repainted.

When coated wire is used, it is necessary to wrap it with felt or metal at the points where it is fastened to the insulators. Thin lead (although certainly a dangerous metal for the purpose, because it sets up galvanic action) has proved effectual for many years, but the hemp with which the wire was covered in this case was carefully re-tarred before the lead was wrapped round the wire. If any damaged places are seen after the wire is up, they must be carefully repaired, or the entire outlay will have been thrown away.

262. The lowest wire should be out of reach from the ground. The lighter wires should, as far as possible, be placed above the heavier ones, so as to give greater stability to the poles; and for the same reason, where arms are used, some of which carry two wires, and some four, the latter should be placed below. If wires of different gauges are fixed on the same poles, they are *very much more apt to get into contact* than wires of equal size, because they do not *keep time* with one another in swinging to and fro.

263. Wires are more apt to get into contact in the vertical than in the horizontal direction; hence there is an advantage in using arms differing about a foot in length, placed alternately. This arrangement has the advantage, also, that if a wire break from its support, it will generally fall clear of the one under it.

Fig. 56 shows the arrangement adopted in the postal telegraphs. The arms are alternately 24 and 33 inches long.

To give greater distance between wires, they should, when fixed each on a separate support, as a bracket, be placed alter-

nately, not oppositely. The distance should increase with the span, and cannot be too great where there is sufficient room on the poles, for wires 17 inches apart are sometimes blown together in storms, even when tightly strained.

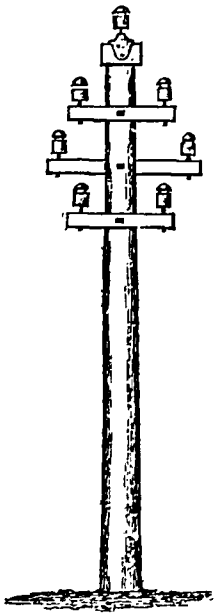


FIG. 56.

Where 20 poles are used to the mile, the distance should be not less than about 12 inches vertically, and 16 inches horizontally, so as to clear the poles well. It is better, as a rule, never to place more than two on an arm; because, when it carries more, it is more difficult to see faults and to repair damages, especially to lift poles when blown down or broken. Snow also will more easily adhere, so as to cause a leakage from wire to wire.

It does not appear that the wires blow into contact much more frequently in long spans than in short ones, provided they are uniform in weight, tension, and distance. When they are properly "regulated" and all is symmetrical, they keep time one with another in their oscillations, but under other conditions they move occasionally in opposite or reverse directions, and in consequence meet. It is not desirable, therefore, to hang wires of different gauges side by side—a No. 11, for instance, on the same arm or in the same vertical plane as a No. 4.

But long spans add to the causes of accident for another reason:

264. Wire is at all times apt to rub or wear because of the friction caused by the wind at its supports, unless they are very hard and smooth, or it is very firmly fixed either by binding or by its tension. It wears more upon a straight line than on a curve, and more when slack than when tight. Some of that

which has been supported on brown ware double cones which are very hard and smooth, on poles set 30 to the mile, is not worn in the least degree, although much of it has been up twenty-four years, and runs freely through them. In other cases, on long spans, and especially where wires pass freely over soft porcelain, the wear has been extremely great. Even so heavy a wire as No. 4 has chafed on spans over 100 yards. No. 11 so frequently breaks that it has been necessary to protect it at the supports by wrapping it with binding wire.

On very long spans it is necessary to shackle off each length so as to transfer the centre of motion to the bolt of the insulator, and allow the wire to swing freely. The "lugs" or projections of iron caps sometimes injure the wire by notching it, as well as by friction. Iron hooks are very objectionable. The wire should always be very tightly bound to the insulator, so as to reduce the friction to a minimum; and it must be recollected that as soon as the zinc is worn off, galvanic action may be set up so as to corrode the iron.

When the position of the poles is altered, as when a line is reset, the wire must be carefully examined, the worn places cut out, or, if the wear is slight, bound over with No. 16 wire.

265. On the older lines the wires were allowed to pass freely through the insulators, and were strained by a drum and ratchet at each half mile. This method has been abandoned in favour of binding to every pole, because under the old method a broken wire runs down half a mile in every case, but on a properly bound line seldom more than 100 or 200 yards, and because the older form of insulator is necessarily bad, leakage occurring in two directions instead of one.

No. 16 charcoal wire is the best for binding: when the line wire is thick, as No. 4 for instance, the binding should be doubled, for a thicker binding wire cannot be applied so effectively.

In binding, the turns of wire should be made always in the

same direction, or they will not be firm; the main wire is twisted somewhat in the process, and when it recovers its normal position it will slacken one side of the binding if the turns are in opposite directions.

The binding stretches, and requires occasional renewal. The old pieces must not be allowed to remain on the main wire, for if they become loose they will cut it by being spun round and round by the wind. They cause a peculiar rattling noise, and can be detected by it.

The distance through which a broken wire will run down depends very much upon the way in which it is bound, as is well shown by the following experiment:—

(1.) On a line of 24 poles to the mile, a No. 4 wire was bound with a single No. 16 wire at each insulator, and securely soldered, so that it could not slip, and was then filed through in the centre of its length. It tore itself from the fastenings throughout the entire distance.

(2.) Next it was bound as before, but soldered at every *fourth* pole; it then broke away from 20 poles only. Here the unsoldered bindings allowed it to slip a little, and thus eased the strain.

(3.) Thirdly, it was bound doubly strong, but not soldered; the first binding stretched a little, and all the arms were strained, but it did not tear itself away from a single pole. The wire, therefore, should be so bound as to slip a very little at each support, and thus prevent the sudden jerk.

266. The top of a pole is the best position for an important circuit. The saddle which holds the insulator must be fixed with screws, as nails split the wood when driven at the end of a pole, and will not bear a strain. If the pole is creosoted, screws are also needed for brackets when the strain is great, as nails will draw out of the wood.

267. When boucherised (coppered) timber is used, all nails, screws, and bolts must be galvanized. It is better also to dip

them in tar before fixing them. The threads of all bolts should be greased.

268. The same *circuit* should always, as far as possible, occupy the same place on the poles, so that it may be readily identified. Wires are generally known by numbers: that on the top of the pole is called *number nought*; the upper one on the side next the road or railway, *number one*; the corresponding wire on the back of the pole, *number two*; and so on. On a railway, when the wires cross the line, it is very convenient to arrange them so that the same order is continued, *number one being always the top wire next the rails or road.* But this cannot always be done, and number one is sometimes the wire to the right hand when one faces the *up* or principal station.

269. When it is impossible to carry the wire free from the branches or leaves of trees, it is sometimes covered with tarred tape or percha tubing, as a partial insulator, to prevent in some degree loss of current.

270. Short pieces of wire must never be left lying about, but should be collected, or placed where they cannot be found by passers-by, as they very frequently cause interruptions to signalling by throwing them upon the line-wires.

271. Thick wires should never be used in crossing a line of railway. If a stay give way, or anything occur to lower a wire, it will be caught by the train, and being too strong to be readily broken, will allow the engine to drag down a considerable length of the telegraph. If No. 12 or 14 wire be used, the engine will snap it, and no great harm will ensue.

272. Stranded wire has been extensively used for long spans; but it rusts much more rapidly than solid wire, owing to its larger surface, and gives way very rapidly where exposed to smoke: steel, or the so-called *homogeneous iron*, is to be preferred when the span is too long for ordinary wire.

273. The weight of a suspended wire causes it to hang in a curve, or to dip. The more it is tightened the less it dips, so

that its *tension* or strain is proportional to its dip. The weight of the wire in the span, or the dead weight on the poles, depends on its size and length. For a line of 20 poles to the mile, where the spans are 88 yards, the ordinary dip is about 18 inches in mild weather, which gives, for No. 8 wire, a *tension or force tending to break the wire,* of 420 lbs., the breaking strain of the wire being 1,300 lbs.

The tensions of two wires of different gauge, the span and dip being the same for each, vary as the squares of their diameters. Thus, if the tension of a span of No. 11 wire be, say 90 lbs., the tension of a similar span of No. 8 will be 160 lbs., because the diameters of the wires are as 3 to 4, the squares of which numbers are 9 and 16.

274. If it be required to increase the distance between the supports, or to increase the *span,* and yet to preserve the same *tension* in the wire, the dip must be increased as the square of the number of times the distance or span is increased. Thus, if for a span of 100 yards the dip be 1 foot, for double the distance, 200 yards, the dip will be $2 \times 2 = 4$ feet; for three times the distance, $3 \times 3 = 9$ feet, and so on.

The mathematical formula is:—

$$S^2 : s^2 : : D : d,$$

where S is the original span, s the proposed span, D the original dip, and d the dip required by the increased span to preserve the same strain or tension.

$$\text{Thus } 100^2 : 200^2 : : 1 : 4,$$
$$\text{and } 100^2 : 300^2 : : 1 : 9.$$

From this formula, which is sufficiently correct for all practical purposes, may be ascertained, not only the dip of any proposed span, but the span of any proposed dip.

Thus, suppose we have 30-feet poles, and wish to learn the greatest distance at which they can be placed apart so as to keep the wires 10 feet from the ground, and to preserve the

strain equal to that given by a dip of one foot in 100 yards, we have—

$$100^2 : s^2 : : 1 : 20,$$

because we have sufficient height to allow a dip of 20 feet. Multiplying together the two extreme terms of our proportion and the two means—

$$100^2 \times 20 = s^2 \times 1$$

$$\text{and } s = \sqrt{200{,}000} = 447 \text{ yards nearly.}$$

275. The *span* being the same, the *dip* will vary inversely as the *tension*. If with a strain of 200 lbs. it dips 30 inches, with a strain of 300 lbs. it will dip 20 inches, and with 400 lbs. 15 inches.

276. The tension is not the same at all points of the curve. It decreases from the supports downwards, and is least at the lowest point; but in lengths under 150 yards the difference is small.

277. When both supports are the same height, the lower part of the curve is in the centre of the span; when one is higher than the other, the lowest part is nearer the lower support, so that the greater part of the weight of the wire is borne by the higher pole. In calculating the strain, the wire should be considered as if prolonged beyond the lower and to a point equal in height to the upper one, and the strain will be proportional to the length thus increased or to twice the distance from the top to the bottom of the dip. It is desirable, therefore, that the two ends of a long span should be fixed as nearly as possible at equal heights.

278. When the tension at the lowest point of the curve is known, that at any other point may be ascertained by adding the weight of a piece of the same wire, whose length is equal to the difference in level of the two points. Thus, the greater the tension and the smaller the dip, the less will be the difference of tension at different points.

If it were possible to pull the wire up perfectly straight, the tension would be equal in all parts.

279. As the tension is least at the lowest point of the curve, a wire is more likely to break at or near its supports, than in the centre of the span; and the centre of a very long span may with advantage be made of lighter wire than the ends; for then the ends will not have so much weight to support, while the centre will be strong enough to resist the tension at the lowest point.

280. The weight of a wire increases with its strength (the quality being the same); the only advantage, then, in using thin wire for large spans is, that the supports have less weight to carry.

281. The greater the dip, the greater the *weight* of wire to be supported, so that there is a point beyond which the dip cannot be increased with advantage; because the tension arising from the *weight* will increase more rapidly than that due to *tightness* will diminish.

For a distance of 1,000 yards, with a wire of No. 8 gauge, the supports being on the same level, the strains will be nearly as follows, as given by Blavier:—

Dip.	Proportional strain at lowest part.	Proportional strain at supports.
186 yards	70	88
218 „	60	81
271 „	50	77
353 „	40	75
516 „	30	81

So that, with a span of 1,000 yards and a dip of 353 yards, the strain at the supports will be the least possible, while with a dip of 516 yards it will be as great as with a dip of only 218 yards.

282. But, in practice, the dip cannot be made as large as those in the table, so that the practical rule for long spans is,

make the supports as nearly equal in height as possible, and the dip as large as you can.

283. As metals expand and contract with the variations of temperature, wires put up in the summer must be strained less tightly than if fixed in winter, or their contraction in frost will break them; and if put up too slack in winter, they will be liable to get into contact in summer.

Although the strength of a wire increases in proportion to its size, yet a thick wire will be as liable as a thin one to be broken by frost; for a thick wire will, obviously, exert more force in contracting than a thin one, and will be more likely to tear down its supports if strained too tight.

Whatever the gauge of the wire, it will always take the same sag for the same span; and therefore, if upon one line of poles one wire has been properly strained with the recognized tension, every additional wire which may be added will be properly strained if it is properly regulated.

284. A wire should never remain tightened up to more than one-third of its breaking strain. There is a great tendency to err in straining too tightly; it must be borne in mind that, however carefully wire may be manufactured, flaws cannot be entirely prevented, nor can they be thoroughly removed by *killing*.

The shorter the span, the greater comparatively is the effect of contraction by cold, and more wires are broken by frost in short than in long spans, when the tension of the wire is the same in each.

285. Iron expands $\frac{1}{14\,6\,1\,6}$ of its length, or about $4\frac{1}{10}$ inches per mile for every ten degrees of heat; so that between winter and summer, or 32° and 62°, there will be on a line of 20 poles to the mile a difference of length in each span of wire of nearly seven-tenths of an inch.

When there are twenty poles to the mile, and No. 8 wire is used, a dip of 14 inches is equivalent to a strain of about 540

pounds, or nearly half the breaking strain. Now by experiment it has been ascertained that between 54° F. and 25° F. the difference in dip is three inches; so that if a wire is pulled up in mild weather to a dip of 14 inches, it will take at 25° a strain of about 700 pounds, the equivalent of a dip of 11 inches, and if at all faulty it will break.

286. JOINTS.—There is nothing more important than the perfect continuity of a circuit, and this can only be attained when every connection or joint is well *soldered.*

No joint is secure as regards conducting power, unless it is *soldered,* however tightly the wires may be twisted together. It is not even sufficient to clean the ends and cast an ingot of metal over them, as has sometimes been done. The same remark applies to every connection exposed to damp, whether a binding screw, or a pair of tinned copper plates tightly screwed together, as in a line testing box or at a tunnel end. Electrolysis, and therefore corrosion, invariably occurs if moisture be present, and the joint ceases to conduct.

A very useful pocket soldering stove has been lately patented. It is a copper box, about 4 inches long and 2 deep, with holes for the admission of air, having a hollow on the upper side large enough to contain sufficient solder for a joint. The box is fitted with a wood handle. The fuel is charcoal, mixed with sufficient saltpetre to light readily and burn steadily.

A twisted joint is apt to break from the hardening of the wire in twisting. The so-called "Britannia" joint is the strongest and best (Fig. 57).

FIG. 57.

It is made by slightly bending up the ends of the two wires, laying them side by side, binding them tightly together with

No. 16 wire, and well soldering the whole. The bent ends should be *cut off close*, to prevent the formation of wind contacts; for when wires are blown together they are frequently hooked permanently by such projections. Joints, even when well made are open to the same objection.

In "terminating" a wire it should never be twisted, or it will break. It must be wrapped once round the insulator and bound as shown in the illustration (Fig. 58). The binding-wire need not be soldered.

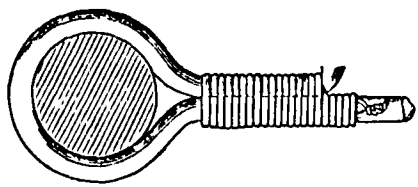


FIG. 58.

Chloride of zinc (or "spirits of salts killed with zinc"), with a little free muriatic acid added to clean the wire, is the best solution for soldering. The rain quickly clears away the excess of chloride; but when copper and iron wires are connected, it is better to wash off the chloride of zinc and to smear the joint with paint or rosin, or even to solder with rosin only, especially in a smoky place, to prevent local action between the metals.

Joints in hard wire must be soldered at as low a heat as possible, so as not to soften the iron, or it will stretch and break where softened, if the strain is considerable.

Wires should never be fixed to wooden buildings. Stranded wire is much less noisy than solid, and is in consequence extensively used for the over-house telegraphs in London.

287. The noise caused when the wires are set in vibration by the wind is sometimes very annoying, particularly when a pole or standard is fastened to a wooden house. To prevent

it, the insulators are sometimes wrapped with vulcanized rubber, or the wire itself is first enclosed in a vulcanized tube, and then wrapped with lead wire about a pound in weight. Strips of wood about 18 × 1½ × 1 inches, grooved slightly to fit the wire, may be placed on each side and screwed together so as to hold it *firmly*. The object in each case is to prevent the vibration, and the proper distance of the *damper* from the support must be found by trial. A short chain, placed between the wire and insulators, is said to have the same effect.

288. INSULATORS.—The surface in contact with the wire should be as small as possible, so as to diminish the leakage. The wire sometimes lies on a knife-edge without being bound to the insulator: this secures the greatest possible insulation, other things being equal. But when a wire passes freely over the insulator, the constant vibration causes it to cut the porcelain or be worn away itself, especially in sandy districts. It should therefore be *bound very securely* to its supports, for loose binding does not stop the wearing action.

For fixing bolts into insulators, *plaster of Paris* mixed with a little liquid glue to prevent its setting too quickly, or *black cement*, composed of 1 part of rosin, 2 of sand, and 1 of smiths' ashes, is used.

Sulphur, in other respects the best of all cements, splits the insulators, apparently by expansion. It was expected that the splitting would be prevented, if the iron were perfectly protected from the sulphur, as when the bolts are covered with ebonite; but it is not so. Oxide of iron mixed with the sulphur is said to render it safe, but it is not necessary to employ sulphur at all.

289. Where the porcelain is exposed to injury from stone-throwing, the insulator is covered with an iron cap, but this covering should be employed as sparingly as possible, as it prevents the rain washing the outer surface. Caps cast with

openings to admit rain have recently been introduced, and will probably be found advantageous.

290. For terminating wires, the insulators should be so fixed that they will take a direct strain. Shackles are to be preferred to insulators fixed upon a pin, for as the iron pin passes through

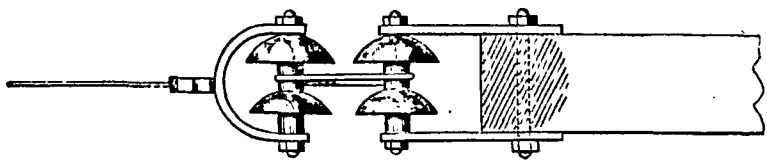


FIG. 59.

the insulator of the shackle, should the earthenware break, the wire will not fall; but on the other hand, as the current can escape upwards as well as downwards, it requires two insulators, or a double shackle, as in the figure, to give the same resistance to leakage as that of an *invert* of the same model and size.

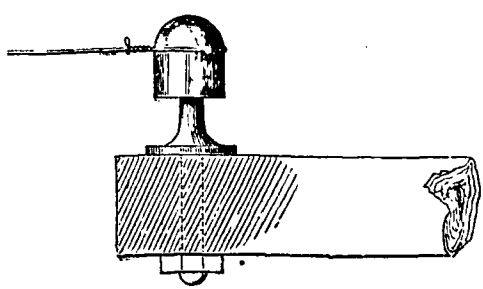


FIG. 60.

Insulators should always be securely fastened to the arms or brackets, for when the pins simply drop into holes they are frequently lifted out by the wind, causing a stoppage.

291. LEADING WIRES INTO STATIONS.—As percha wire is very perishable when exposed to air and light, it is imperative to leave as little as possible uncovered, and to enclose it in

an iron pipe or a well-made wood casing, carefully fitted and painted.

The percha should be covered with tape, and varnished with Stockholm tar, in outdoor work, and wound with tape saturated with genuine white lead paint *without turpentine,* for indoor work. The length left exposed must have a double coating of tape and tar.

As the dirt on the exterior of percha conducts when damp, a short length of the loop which extends from the casing to the line wire should be protected from rain by a porcelain or stoneware bell or large tube, so that a portion of dry surface may break the line of leakage.

However well covered with tar exposed percha may be, it needs frequent re-tarring, or it will decay in time.

292. In fixing earth-plates care must be taken that the principles laid down in section 98 be complied with, so that a perfect earth may be obtained.

Occasionally an earth cannot be found; a return wire is then necessary. It is generally better to use a return wire for bell circuits of less than half a mile. It, of course, need not be insulated.

293. Over-house Wires.—When wires are carried over houses it is better to use a light strand, because it is not so liable as a solid wire to be set into noisy vibration by the wind. It may, in smoky towns, be protected with a wrapping of tarred tape. Over-house wires are erected in long spans, and are shackled off at every support, so that they may not be worn by friction at the insulators, and that each span may be independent as to stability. The poles are iron; they are light, and are slipped into a cast-iron saddle, which fits upon the ridge of the roof. They are well stayed in every direction, the pole being arranged so as merely to carry the weight of the wires.

Sometimes a number of insulated wires are made into a cable, which is suspended by hooks from a pair of wires of the usual

kind, carried in the manner described above. These cables must necessarily be light, and their insulation is consequently defective; it is, however, capable of considerable improvement.

The great defect of over-house telegraphs is in their insulation. Shackles do not in any case insulate well, and they soon become coated with smoke, while from their position they cannot be frequently cleaned. The author cannot recommend their employment as portions of long circuits, though they are sufficient for local telegraphs.

294. UNDERGROUND WIRES.—Underground wires are either drawn into pipes, or laid in troughs fitted with a moveable cover. It is very much more easy to place the wires in a trough than to draw them into a pipe, and there is less chance of injuring them; but it is much more difficult to execute repairs in a trough, and practically it does not appear that the process of drawing into a pipe injures the wire if ordinary care be used.

When pipes are employed, the entire length may be replaced by new wire, without interrupting the communication for an instant, or even opening the ground except at the drawing-in boxes; while if a trough is used it must be opened throughout, unless it has been constructed so as to allow the cable to be drawn out, in which case it would be more expensive than pipes. The plan which has been pursued for many years in London and the larger towns is to lay down a pipe under the flag-stones, amply large enough for all the wires likely to be required. Oblong "drawing-in" boxes, 30 inches by 11 inches, and 12 inches deep, with lids formed of an iron frame, into which a piece of flag-stone is fixed, are placed at every 100 yards if the line be straight, and nearer if it be curved. The pipes should be well cleaned, and tarred inside while hot, to prevent rust, for rust causes the wire to adhere so strongly to the iron that it is difficult to detach it.

The wires are sometimes made into cables, 400 yards in length, with a very slight twist, and covered with braided hemp like the

handle of a whip, but it is more usual to spin tape around each separate wire, and simply to tie them together as a bundle, cutting the ties off before they enter the pipes. In either case the percha, tape, and hemp are well covered with Stockholm tar. Stockholm tar preserves percha more completely than any other substance, but gas tar is injurious.

295. When a length is found to require renewal, a new "*cable*" is connected in a loop between it and the next length, and as the defective piece is drawn out the new piece is drawn in. The defective wires in the old *cable* are repaired at the factory. Thus the whole of the *street-work* can be replaced by new wires without interrupting the communication. Extra or *spare* wires are always provided when a new length is drawn in, so that it may not require renewal until several wires have failed.

It is impracticable to draw out a portion of the wires, because the friction of one wire upon another would cut through the coating. Nor can new ones be drawn in without great risk, unless both old and new have been made into a cable and covered with hemp or canvas. But the objection to covering a cable thus is, that should it rot partially or be injured, the defective portion will strip off and choke the pipe. When the wires are taped *singly*, the choking is prevented.

It is always desirable to make all the joints at the same part of the cable, so that they may be easily found, because although joints made in the factory should be as sound as any other portion of the sheathing, they cannot either be so well made or so carefully tested in the open air. At each set of joints the wires are labelled.

296. Faulty wire should not be used for permanent work, even if it appears good enough as regards insulation for the purpose, because a fault always increases and will in time become serious.

297. TUNNELS.—Percha wire, well taped, tarred and sanded,

is laid in a wood trough fixed to the wall. A cover is placed over it, coated with zinc, to prevent accidents from the cinders thrown out by the engines. In fixing the cover great care is necessary to prevent piercing the wires, and it is better not to nail it on, but to *tie* it.

Sometimes an iron pipe is used instead of the trough.

298. Percha wires have occasionally been laid in a pipe filled with Stockholm tar, which it is expected will preserve the percha for a long time.

The pipe is fixed as level as possible, and ⊥ pieces, closed by screwed covers, are introduced at each 100 yards.

The wires are drawn in, all at the same operation, through a mixture of boiled tar and linseed oil, slightly warmed to make it more fluid. They will carry a portion of tar with them, and the pipe may be afterwards filled by screwing on vertical pieces at each end, into which the tar may be poured. The pressure of the head of tar will carry the air out before it, which will escape at the ⊥ pieces which are left open. Each opening should be closed as the tar reaches it. If the tunnel is too long for the pipe to be filled from the ends, vertical pipes for pouring in can be fixed at the ⊥ pieces. The objection to it is that the tar will harden in time, so that the wire probably will not be drawn out again without injury.

299. Wire is sometimes insulated by being imbedded in asphalt.

The best results have been obtained in this way. A wood trough, strong enough not to warp or bend, is fixed to a wall. The bottom of the trough is covered with a layer of hot bitumen, softened with Stockholm tar, but it must be made of such a consistence as not to crack in the coldest weather, nor to become so soft in summer as to permit the wires laid in it to sink into contact one with another, a matter of very great difficulty.

After the bitumen has cooled, the first layer of wires is placed upon it, the wires being kept from touching one another by

moveable combs, while they are covered with the mixture. This must be sufficiently warm to adhere perfectly to the first layer, yet not so hot as to melt it. More wires are then laid, and the operation is repeated until the trough is full. Bare iron or copper wire can be used, or defective percha wire.

As moisture prevents the blending or adhesion of the several layers of bitumen, the operation cannot be carried on in damp weather. If a drop of rain fall into the trough, it will be converted into steam by the hot mixture, and will cause a hole, perhaps not large enough to be observed, but sufficient to let in water and create a fault.

Mineral bitumen succeeds better than that made from gas tar, and Stockholm tar is to be preferred to gas tar, for the latter causes the mixture to become brittle after a time.

A serious objection to the system is the difficulty of repairing it should it become faulty.

Old gutta-percha wire, too much decayed for ordinary purposes, may be utilized in other ways. It may either be made into a cable or bundle of wires, covered with canvas, and injected with a very soft mixture of Stockholm tar and asphalt by the vacuum process; or, after having been well rubbed with a somewhat harder tarry mixture to fill up the cracks and other defects, it may be laid in a trough filled with the same material. These methods give a very fair insulation, except in places where it is constantly wet.

300. JOINTING COVERED WIRE.—Unless a professional jointer is employed who can be held responsible for his work, no one but the line-man in charge of the work, who will have the trouble of repairing it if defective, should be entrusted with the delicate operation of making joints.

Cleanliness is most essential to success. The fingers should be used as little as possible, and must be kept very clean.

Prior to making the joint, the gutta-percha is removed from the ends of the wires for about 1½ inches, and the copper wires

are carefully cleaned by scraping ; the wires are twisted together for 1 inch, the sharp ends being closely trimmed off. The joint is then soldered with *rosin* and good soft solder containing a sufficiency of tin.

After this the gutta-percha is scraped, or very carefully pared back for 2 inches, to remove its outer surface, which is oxidized and will not join properly; the wire joint is covered with Chatterton's compound, and the gutta-percha heated on both sides and tapered down over the joint until that from each side meets. The junction is completed by means of a warm jointing tool, care being taken to mix the gutta-percha well without burning.

As soon as this has cooled, another coating of Chatterton's compound is spread over the gutta-percha, taking care not to burn the compound.

A new and clean sheet of gutta-percha is then heated by means of a spirit lamp, and while so heated carefully stretched so as slightly to thin it. Then, while it and the Chatterton-coated joint are still hot, it is laid on the joint, and pinched tightly round it with the finger and thumb, after which it is trimmed off close with scissors. The seam is again pinched, and carefully finished off with a warm tool, so as to mix the gutta-percha of the two sides, and the coating of the wire itself, well together.

The joint, when cool, is again covered with Chatterton's compound, and a longer and larger sheet of gutta-percha is laid over it, pinched, cut, and tooled off as before.

When the joint is complete, another coating of Chatterton's compound is applied over the whole, well tooled over the joint, and, when cool, rubbed with the hand, well moistened, till the surface is smooth.

The mixing of the old and the new gutta-percha is most important, and joints generally fail from this having been imperfectly done, or from the percha being overheated.

301. *Second Method.* (Sabine's "Electric Telegraph.")

Cut the ends of the core flush.

Warm the percha on each wire with a spirit lamp for 3 inches, and, when soft uniformly all round, push it back so as to form a knob.

Cut off the exposed wire, leaving sufficient to form a joint.

After soldering with rosin, wash the wire with naphtha, warm it, and coat it with compound.

Warm one of the knobs, and draw it again over the wire up to the other knob; trim it, knead it well into the second knob, and coat with compound.

Then draw the second knob over the first, coat with compound, and cover with sheet percha as in the former method.

A very excellent temporary joint may be made by drawing a piece of vulcanized rubber tube over the ends of the percha after having soldered the wire, and wrapping it tightly with twine.

PART VIII.

ORDINARY TESTING.

302. It is important that all the principal circuits should be tested daily for insulation and resistance, and that the test be so recorded as to be capable of being reduced into units of resistance. These tests will point out leakages and faulty connections, so as to enable their removal to be effected, in very many cases, before they interfere with the working of the circuit, besides giving the data necessary in testing for the distance of faults.

303. The line wires at all important stations are connected to *terminal* screws in a *test-box*, in which are fixed similar binding screws joined to wires leading to the instruments and to the earth.

In the daily testing, the distant station disconnects the line wires at a fixed time for a certain number of minutes. The insulation test is then taken by connecting the battery, galvanometer, and line, as shown in the diagram.

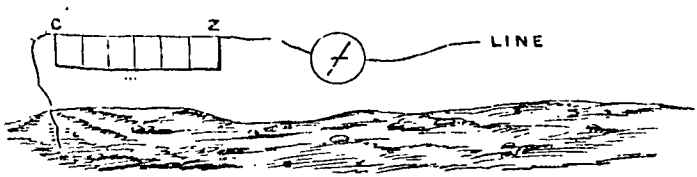


Fig. 61.

The distant station next puts the line wires to *earth* for a second fixed period, by screwing a bright copper wire to the

earth terminal, and to all the line wires, which are still left disconnected from their respective instruments. The connections at the testing station are the same as in the diagram, but the distant ends of the wire, instead of being free, are connected to the earth. The *continuity* or resistance test is then taken.

304. Blavier, in his Manual, describes the French method thus, A and B being the two stations:—

A sends a current through his "detector" during two minutes.

For the first minute B leaves the wire disconnected, and during the second minute puts it to earth through his own detector.

Each station registers the results.

During the next two minutes B sends the current, and A makes the changes previously made by B, each registering as before.

The tests made when the wires are *disconnected* show the leakage or loss of insulation; those made when the wires are *to earth* give the resistance of the circuit.

The tests taken at the opposite ends never agree, the resistance of the wire making a distant fault appear smaller than one near at hand, not to mention other obvious causes of disagreement.

305. Even where only the very roughest tests are required, the battery power must be so regulated as not to deflect the needle of the galvanometer to the full extent of the scale, for two wires may differ very much in resistance, and yet appear to test alike if both give what is called *full deflection.*

306. Each principal office should be provided with the means of reducing the daily tests into *units of resistance;* for it is obvious that by no other method than the reduction of each test to a common standard of resistance, can the observations, taken at different times and in different places, be compared.

Accuracy sufficient for ordinary purposes may be attained by the use of a *tangent* galvanometer, having its scale divided as shown in paragraph 128; with a delicately balanced needle, and a standard coil of 500 or 1,000 ohms' resistance.

As the graduation of this galvanometer is correct throughout and the friction of the pivot the same at all angles of deflection, a much greater extent of scale is available than in any other instrument. If the coil is wound with two equal wires, so as to divide it into equal portions or halves, one-half may be used for strong currents, or for resistance tests, and the entire coil for weak currents, or insulation tests; the readings obtained with the half-coil must be multiplied by two. Or a shunt may be attached to it, which is a wire connecting the two ends of the galvanometer coil, so as to divert a portion of the current and reduce the sensibility of the instrument.

307. First test the strength of the batteries, by ascertaining what deflection will be obtained upon the *standard resistance* R, as in the following diagram. This is called *taking the constant* of the instrument.

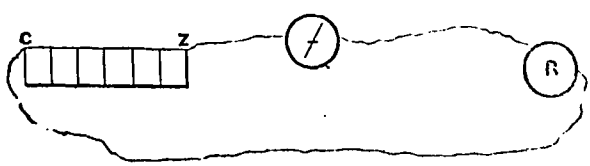


FIG. 62.

Then test for insulation and resistance in the manner already described.

When a tangent or any horizontal galvanometer is used, great care is necessary to avoid the disturbing action of masses of iron, the electro-magnets of the instruments, and of the currents through the wires which pass under the desks. If a more suitable situation cannot be found for the instrument, it may be placed in an iron box without a lid.

308. The daily tests taken by this method by a tangent

galvanometer, having a scale of tangents, may conveniently be recorded in the following form :—

Date.	Constant. or Reading through 1,000 ohms.	Wires.				State of the Weather.
		No. 1.		No. 2.		
		Insulation.	Resistance.	Insulation.	Resistance.	
Feb. 19	60	12	30	10	50	Rain.

These readings can be reduced to units by inverse proportion, the less the resistance the greater being the deflection, thus :

12 : 60 : : 1,000 ohms : 5,000 ohms = the insulation test of A in units ; that is to say, if 1,000 ohms give a deflection of 60°, a deflection of 12 will represent five times the resistance, or 5,000 ohms. Or, more simply, because the standard is 1,000, add three ciphers to the reading obtained upon the standard, and divide it by the reading obtained upon the wire thus :—

$$\frac{60{,}000}{12} = 5{,}000. \qquad \frac{60{,}000}{50} = 1{,}200.$$

If the shunt be used, the reading must be multiplied to render the test comparable with others taken without the shunt ; thus, if the battery and standard coil give 60° *with* a shunt, which reduces the sensitiveness of the instrument to one-tenth, and the wire to be tested gives 60° *without* the shunt, the reading taken with the shunt must be multiplied by 10, and be recorded as 600, while the reading taken upon the wire without the shunt will be recorded as 60 only.

By means of the shunt, the galvanometer which is used for testing the line may be made available for testing the condition of a battery. The resistance of the shunt can be adjusted by trial, so that the battery shall, when in good order, give a deflection of 30°. But it is more convenient to wind a few turns of

thick wire over the fine wire coil so as to form a continuation of it, and to fix a third terminal at the point where the thick and fine wires join. The former alone will test a battery, the two together a line wire.

309. The most accurate methods of testing are by means of the *differential galvanometer* (127), or the *Wheatstone's balance* (417), and a set of resistance coils (78), and it is desirable, occasionally, to employ one of these more accurate methods.

310. In testing a line wire by the "differential" for insulation, the connections are made thus :—

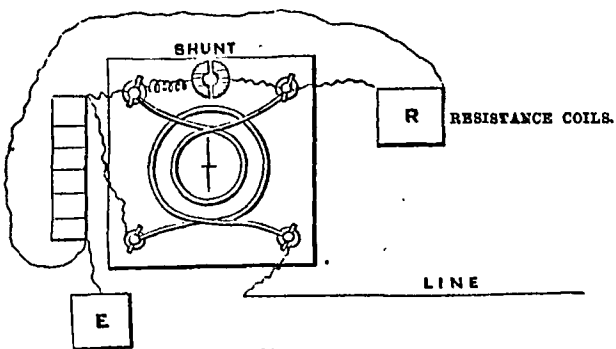


FIG. 63.

In testing for resistance or continuity, the line can be connected to earth at the distant end, or, what is better, looped with another wire whose resistance is known, or which is exactly similar, thus :—

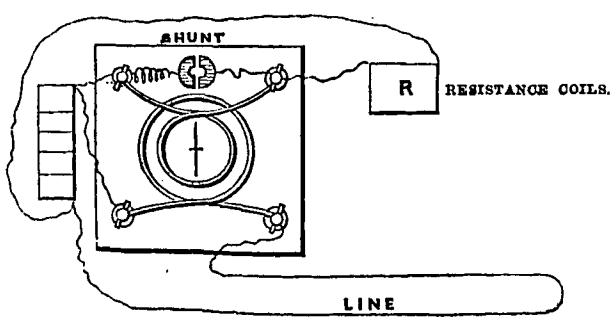


FIG. 64.

When the shunts are used the reading of the resistance coils must be multiplied by the *value of the shunt*—10, 100, or 1,000, as the case may be.

311. The use of the Wheatstone's balance is fully described in treating of Submarine Cables.

For ordinary line testing it may be simply constructed, thus:—

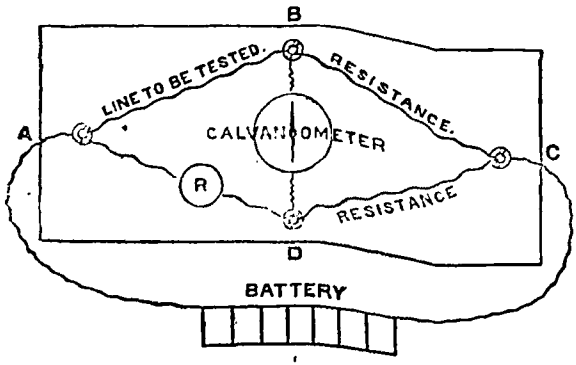


FIG. 65.

B C and D C are two wires equal in resistance,—about ten ohms is sufficient. The line A D with R represents the resistance coils, and A B the line to be tested. A and B will be the two ends of the loop in a loop test, B the line wire, and A the earth, in a test to earth, the distant end of B being put to earth. The connections of the battery and galvanometer are shown in the diagram, the small circles representing binding screws.

The resistance at R must be altered, until the needle remains unmoved when battery contact is made and broken, when it will be equal to the resistance of the line tested.

312. When better apparatus is not to be had, the ordinary vertical "*detector*" may be used, but it is not susceptible of accuracy. Its scale is not correct above 20°, and the friction of its pivots interferes with the readings below 40°. The most trustworthy part of the scale lies between 40° and 60°.

Such a number of cells should therefore be used that the

deflection will range between these points. Multiply the reading obtained with the smaller number of cells, so as to increase it to what it would have been with the greatest number used, if the detector had been able to register so large a deflection.

Suppose 1 cell gives 60° on the standard coil of 1,000 ohms
That 10 cells give 50° on wire A;
And that 40 cells give 40° on wire B.
Register the tests, thus:—

1 cell	through	1,000 ohms	gives	60° ×	40 =	2,400[1]
10 cells	„	wire A	give	50° ×	4 =	200
40 „	„	wire B	„	40° ×	1 =	40

To reduce the tests to units of resistance, employ inverse proportion, because the greater the deflection the less the resistance; thus, for wire B:—

$$40° : 2{,}400° :: 1{,}000 \text{ ohms} : 60{,}000 \text{ ohms};$$

or, $\frac{2{,}400 \times 1{,}000}{40} = 60{,}000$ ohms, the resistance of B.

This is at best but a very rough measurement, but it is much better than a mere record of the number of degrees of deflection.

The ordinary detector can only be used for measuring resistances with anything approaching accuracy when we employ but one deflection, and reproduce it by varying battery power. Thus if with 24 cells a reading of 48° is obtained upon the wire to be tested, and if we find that one cell through 500 ohms gives the same reading, then by multiplying the number of units of resistance obtained with the one cell by 24, we have 12,000 ohms as the resistance of the wire.

But it is seldom that a series of cells are exactly equal in power, and the single cell may in some cases be even doubly as powerful as any one of the others. It is only where the

[1] Because if one cell gave a current whose strength was 60 on the coil of 1,000 ohms' resistance, 40 cells would have given 40 times as much.

resistance of the battery and detector is so small, compared with that of the line to be tested, as to be neglected, that the deflection of a galvanometer increases in proportion to the number of cells used.

313. In order to compare the insulation of line wires of different lengths, the insulation *per mile* must be ascertained, otherwise the largest wire would appear the worst; for obviously, the longer the line the greater the total leakage.

Multiply the insulation test of the wire by its length in miles.

When the insulation is good, and equal throughout the circuit tested, the leakage will increase in direct proportion to the length of the wire, irrespective of its thickness or conducting power, because the resistance of the wire is exceedingly small compared with that of the insulators, and may be neglected.

Thus in an actual test the wire A had a leakage equal to 29

„	„	„	B	„	„	30
„	„	„	C	„	„	50
					Total leakage	109

The three wires, when connected at the testing end, and left free at the distant end, had a leakage of 110.

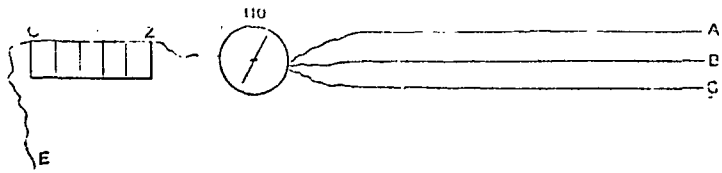


FIG. 66.

When looped so as to form one continuous wire, free at the distant end, the leakage was still 110, or sensibly the same.

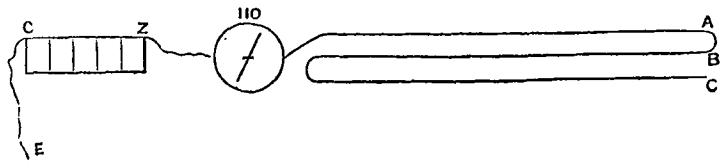


FIG. 67.

The experiment was repeated and extended to other wires with a similar result.

In this case the resistance of the insulators was very great compared with that of the wire, as much as two million ohms, or two *megohms*,[1] per mile, so that an increase in the distance of the points of leakage did not sensibly affect its amount by lessening the force of the current, nor was any sensible amount lost by leakage. But on a wet day, three similar wires, whose respective leakages were 196, 185, and 141, making a total of 522, when looped as in Fig. 67, gave a test of only 476; the distant portions of the wire being tested in reality by a current weakened by the leakage in the nearer portions.

When the insulation is so bad that the resistances of the supports bear a nearer proportion to that of the wire between them, a thick wire will test worse than a thin wire, *and a circuit of many instruments better than a direct circuit in which there are none except at the terminal stations.* Yet the thicker wire gives better signals, because the gain by greater conducting power more than makes up for the loss by greater leakage.

The increased leakage arises partly from the greater conducting power of the larger wire, from the surface in contact with its supports being increased by the increased size of the wire itself, and that of the binding by which it is fastened, which is necessarily stronger.

For instance, to take actual results obtained upon wires whose insulation is probably below the average, as they run for a considerable distance near the sea.

In fine weather both wires tested alike, their insulation resistance being 79 million ohms per mile. On a very wet day, for a portion of the same distance the No. 4 had R = 70,000, and the No. 8 = 78,000.

---

[1] A *megohm*, or great ohm, is one million ohms.

Taking a circuit better situated as regards insulation—

Insulation Tests of Two Wires, on the same poles, between Dublin and Belfast—tested at Dublin.

Date.		Weather. At Dublin.	Weather. At Belfast.	Insulation per mile No. 4 wire.	Insulation per mile No. 8 wire.	Remarks.
1868.						
February	8	Dull	Fine	682,500	787,500	
,,	7	Damp	Damp	131,200	157,500	
,,	15	Dull	Fine	2,100,000	2,100,000	
,,	10	Damp	Fine	210,000	315,000	
,,	24	Damp	Dull	91,900	112,900	
,,	29	Fine	Damp	787,500	787,500	
March	11	Wet	Rain	157,500	210,000	
April	11	Fine	Fine	38,750,000	38,750,000	
,,	8	Wet	Damp	525,000	1,050,000	
,,	7	Damp	Misty	.....	787,500	
June	5	Fine	Fine	78,750,000	78,750,000	
,,	6	Dull	Misty	921,300	921,300	
November	23	Damp	Fine	656,300	918,500	
,,	25	Wet	Rain	131,000	183,800	
December	26	Damp	Damp	1,312,500	1,365,000	
,,	21	Rain	Rain	131,300	131,300	Working well.

Maximum insulation per mile No. 4 gauge	78,750,000
Minimum ,, ,, ,, ... =	91,900
Maximum ,, ,, No. 8 gauge	78,750,000
Minimum ,, ,, ,, ... =	112,900

314. When a wire is tested for resistance by putting the distant end to earth, the result is apt to be interfered with by earth-currents which aid or oppose the testing current. So much is this sometimes the case, that it is impossible to ascertain the true resistance of some lines by this method.

When the earth-currents are not very strong—that is, when they indicate upon the instrument used only a few degrees of deflection—and are steady without variation, their effect can be

eliminated by taking the mean of measurements made with copper (positive) and zinc (negative) currents; and with a differential galvanometer they can be counteracted by taking the deflection given by the earth-current as the *zero* of the instrument instead of 0°.

The *loop method*, where the wire is disconnected from earth and looped with another similar wire or one of known resistance, is more accurate; but unless this test is made in fine weather, the leakage from one wire to the other decreases the resistance of the loop. Again:—

The battery must be insulated from earth, or at any rate neither pole must be put to earth, because the leakage to earth at each insulator tends also to decrease the apparent resistance, especially in damp weather, or with defective insulation. For instance, two wires on the same poles disconnected and looped at the distant end had a resistance of 6,475 ohms, when tested thus—zinc to one line-wire, copper to galvanometer, galvanometer to the second line-wire,—being in this case disconnected entirely from earth. But when the zinc pole and the line-wire attached to it were put to earth, the apparent resistance fell to 5,250 ohms. The resistance of insulation (one wire disconnected) was 9,250 ohms, the weather being damp.

TESTING FOR FAULTS.—The following are the principal faults of a circuit:—

315. *Disconnection*, or loss of continuity, when the circuit is *broken*, so that the current will not pass. When a current is sent on the line-wire, the galvanometer needle at the sending station does *not move* at all.

316. *Partial Disconnection*, when the resistance is *increased* by a rusty or badly soldered joint in the wire, dirt in the pivots of a key or relay, &c. The *received* current is enfeebled, less current than usual leaves the sending station, and the needle or galvanometer at either station *moves less strongly*.

317. EARTH.—When the wire *touches the ground*, or some conductor in connection with the earth, such as a wet wall, another line-wire, a stay wire, &c., the current passing out from the sending station is always increased; the needle or galvanometer there moves *more strongly* than usual, because the resistance of the circuit is *lessened* by an extra path being open to the current, which splits between its own wire and the fault in the inverse ratio of their resistances. (211.)

But the current received at the stations beyond the fault is *lessened*, because part is led away by the fault. Should the resistance of a fault be very much less than that of the circuit beyond it, no appreciable current will pass to the distant station.

318. PARTIAL EARTH.—The current dividing at the fault F. Signals weakened at receiving, strengthened at sending station.

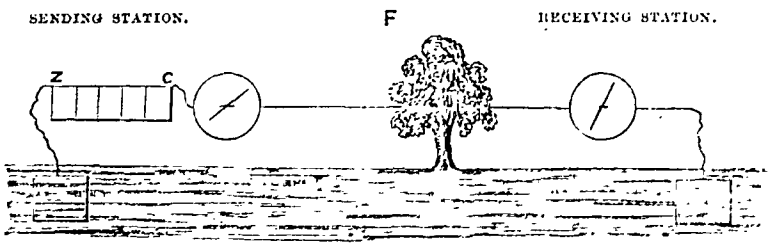


FIG. 68.

319. DEAD EARTH.—All the current passing through the fault. Signals still stronger at sending station; no signal whatever beyond the fault F.

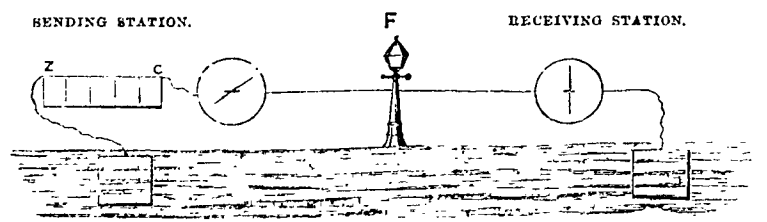


FIG. 69.

320. CONTACT.—When one wire touches another, the current divides at the fault between the three paths open to it.

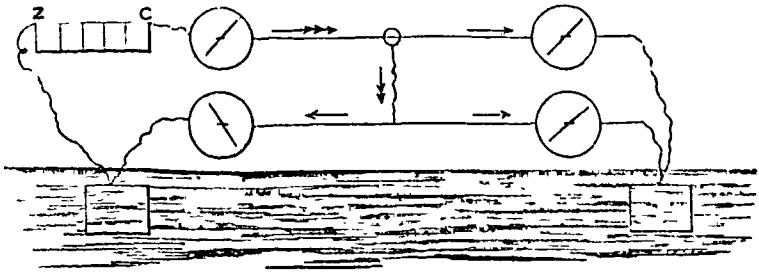


FIG. 70.

When a contact exists between two or more wires *leading into the same office*, if one of the instruments be worked, part of the current returns by the other wires, and causes their instruments to move also, but in a contrary direction. Another part goes on to the distant station by the wire on which it was originally sent, and the remainder to the distant stations by the wires in contact, moving the instruments connected with them in the same direction as that of the instrument on the original wire. When there is contact with a wire *not leading into the testing station*, the fault will appear to be *earth*.

321. WEATHER CONTACT.—In wet weather, the dampness of the insulators enables part of the electricity to leak or escape from one wire to another, and to the earth. The current entering the other wires produces effects similar in appearance to, though less in amount than, those caused by actual metallic contact between the wires. This fault is called "*weather contact*," and may be prevented by providing a good earth wire (212), so fixed as to intercept the current in its transit from one insulator to another, and convey it to the earth.

The signals at the *sending* station will appear stronger, while those at the *receiving* station will be weakened, as in the case of partial earth.

322. DEFECTIVE EARTH CONNECTION.—When the earth wire or plate is defective, and offers a sensible resistance, a current sent on any one wire connected to it divides itself among the remaining wires, making them appear to be *in contact,* because it is usual to connect all the circuits of a station to one and the same earth wire, which is led to the earth plate.

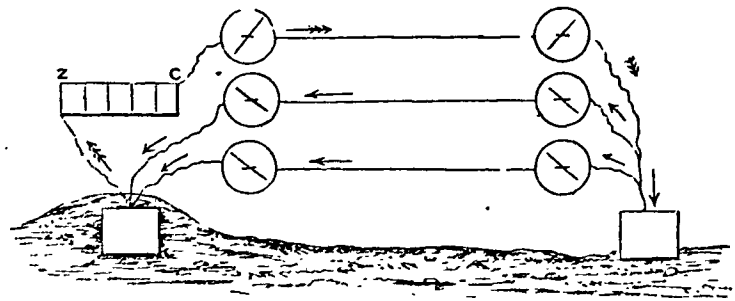


FIG. 71.

In the above diagram the right-hand earth is supposed to be defective, and the arrows show the path of the current dividing itself between the earth and the wires. In the following diagram the earth wire is supposed to be broken; in this last case no

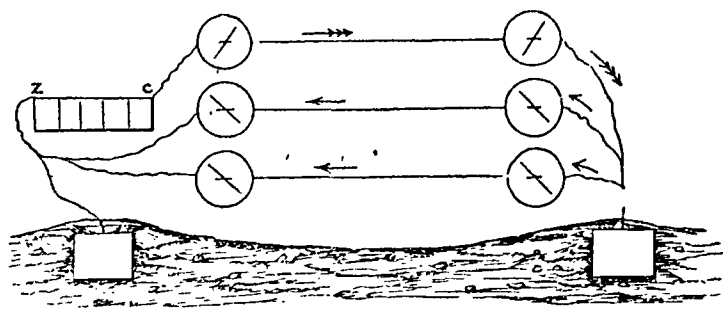


FIG. 72.

current will pass to the earth at all, even at the receiving end, because the earth forms no part of the circuit. When the defect is small, it may be mistaken for "weather contact;" but the leakage from one wire to another, from damp or want of insula-

tion, is always *greatest in wet weather*, while the apparent contact from defective earth is *greatest in dry weather*, because damp increases the conducting power of the soil and improves the earth.

323. TESTING AT A TERMINAL STATION.—*First make certain that the fault is not in your own station.*

Ascertain whether a current leaves your station, by pressing the key or moving the handle of the instrument. If the needle or galvanometer does not move, put earth on at the test-box; should it still remain unaffected, the fault is in the office, being either disconnection of a wire, failure of the battery, or a break of continuity caused by dirt in the apparatus.

If the needle is strongly deflected when the earth is on at the testing box, the fault is disconnection on the line, or at a distant station.

Put the galvanometer used for the daily tests (306) in circuit at the test-box between the instrument and line-wires, and move the key of your instrument.

(1.) If the needle moves more strongly than usual, the fault is probably earth on the line.

(2.) If it moves weakly, or not at all, there may be total or partial disconnection, either on the line or in the office; earth in the office, or a fault in the batteries.

324. Put earth on the galvanometer in place of the line.

If the needle now moves strongly, the fault is want of continuity on the line. If it still does not move, or moves weakly, there is a similar fault in the office.

325. If the needle of your instrument, or the galvanometer attached to your printing machine, moves, while that of the test-box galvanometer does not, there is earth between the two, the place of which may be found by disconnecting each part of the circuit successively, commencing at the test-box.

When the wire which makes earth has been disconnected, the instrument needle will cease to move, because the circuit has been broken.

326. Should neither needle move, the batteries are out of order, or the circuit broken.

Try if the batteries produce a current, by putting a detector in circuit between the two poles, or between the battery terminals of the instrument, or touch these terminals with one finger of each hand, so as to feel the shock.

327. Should the batteries be found in order, connect a piece of good wire to the instrument terminal of the test-box, and with it touch successively the several connections and parts of the apparatus, commencing with the one nearest the test-box. When the needle moves, the fault has been passed, and will be found between the point last touched and the one touched next before it.

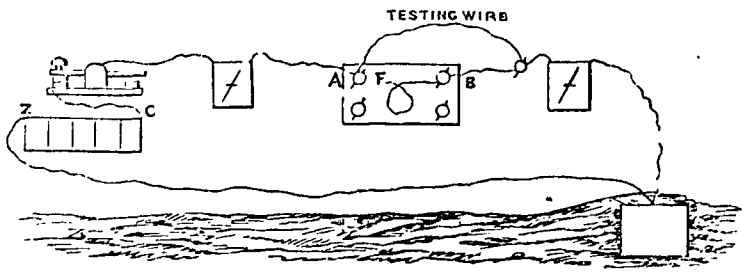


FIG. 73.

Let the wire of the relay A F B be broken at F; touch the terminal B with the testing wire, the needle is unaffected. Touch A, and it moves, because the broken place has been bridged over.

328. If the batteries are faulty, they must be tested trough by trough and cell by cell by a *quantity* detector (71), till the fault is discovered.

Remove the faulty battery, or connect it across with a wire.

329. Lacquer or dirt in the pivots of a key or relay will often cause disconnection, especially at the stop upon which the key of a printing instrument lies, or the bridge which connects the springs of a needle instrument.

If best salad oil be applied to the pivots and points of contact

of printing keys, the dirt will never harden sufficiently to break the connection. A film of oil secures a better contact than a dry surface.

330. It must be recollected that a strong current will pass an imperfect connection, while a weaker current would be stopped by it. Thus it frequently happens that a dirty key will transmit signals perfectly well if the circuit is shortened by putting earth on, when no current will be sent at all when the entire line is open.

In all tests for want of continuity, a very feeble current should be employed, because a strong current may pass an imperfect joint and prevent its being discovered. Use one or two cells only.

331. If everything is right in the office :

EARTH.—Send a current from the test-box through the testing galvanometer. Should the resistance of the wire be about the same as usual, and the needle move about as strongly as in the usual daily tests for resistance, the fault is *earth* at or very near the distant terminal station.

332. Should the needle be more strongly deflected than usual, the fault is nearer the testing station.

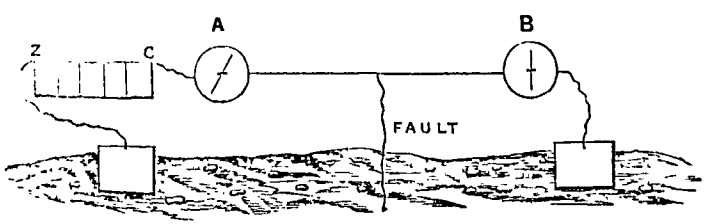


FIG. 74.

Suppose it to be between the stations A and B, and that A is testing.

(1.) Let A disconnect the wire, and "say when done." The current will not pass now, because the earth is beyond A.

(2.) Let the wire be "joined up as usual" at A, and discon-

nected at B. Breaking the circuit at B will not affect the detector, because all or almost all the current will go to earth at the fault, showing that B is *past* the fault.

333. Or get each station in succession to send you a current, and try if it reaches you. This method is not certain, as many persons can unscrew a wire, so as to disconnect it, but are not to be depended on to send a current. Besides this—

334. Disconnection and earth also are not always total, so that a feeble current may reach you from a distant station, even when there is partial earth between that station and your own, or when there is partial disconnection.

335. If you have no means of speaking direct, send a message by some other route, instructing the station to disconnect or put earth on the wire at a certain time, for five (or fewer) minutes. Thus: "Disconnect —— circuit from 10.20 to 10.25; say if you will do so. Time 8.10."

The reply should be, "I will disconnect —— circuit from 10.20 to 10.25. Time 8.20."

336. CONTACT.—When a current sent on one wire returns by another, and moves the apparatus connected with it, disconnect both instrument wires from the line-wires at the test-box. Send a current on one line-wire and place the galvanometer in the other, thus:

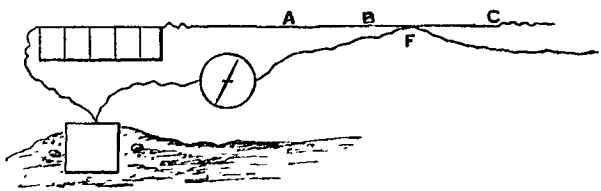


FIG. 75.

Let F be the place at which the wires are in contact, and A B C stations at which the wires can be disconnected: the fault being between B and C, part of the current sent on the upper wire will return by the under, and move the needle of the galvanometer attached to it.

Instruct station A to disconnect either of the two wires, and to say when he has done so; the deflection will cease, showing the fault to be beyond A. Instruct A to join up, and B to disconnect; the same result will follow.

But when C disconnects, the deflection will continue, showing that C is beyond the fault. Care must, of course, be taken not to be deceived by "weather contact," or the ordinary leakage of one wire into another.

337. *Never test for contact by having the earth put on at the testing stations: this method is liable to great error, and has led to much inconvenience.*

If *a very good* earth be put on *beyond* the fault, and very near it, it will cause the contact to disappear almost entirely, because the resistance of this new path will be very much less than that of the other wire.

And if the earth be *imperfect*, and be put on between the original station and the fault, the contact will not disappear, especially if the wires be clean, so that the resistance of the points in contact be very little.

The fault may appear less, but unless care is taken that the testing battery be not strong enough to deflect the needle to its full extent, the variation in the resistance of the circuit may escape notice.

338. When a contact occurs between the two wires of a branch line forming a loop of the main circuit, it will appear like an earth to the stations upon the branch, while the other stations would report inattention at branch stations, because they would be able to speak to all stations except those on the branch.

339. DISCONNECTION.—Want of continuity, the wire broken on the line, or removed from the instrument at a station.

If, when a current is sent from the test-box to the line, the needle does not move, or moves feebly, there is partial or total loss of continuity. The resistance of the wire is increased in

the first case, enfeebling the current; and the circuit is entirely broken in the second case, stopping the current altogether.

340. Suppose the disconnection to be total, and to lie between A and B.

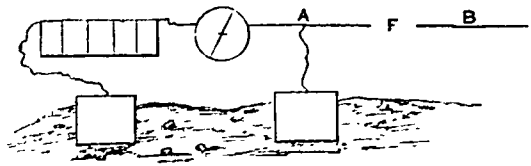


FIG. 76.

Send a current to line through the detector, and instruct the nearest station to put earth on and "say when done."

If the needle moves, the fault is beyond the station at which earth was put on.

Let the earth be taken off at the first station and put on at the next, and so on till the fault has been passed, when the needle will remain stationary as at first.

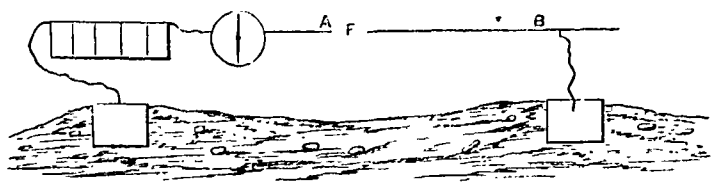


FIG. 77.

Or each station along the line may be instructed in turn to send a current. If a current reaches you, the wire is perfect as far as the station which sends it.

But this method is liable to error from the want of care at the stations sending the current.

341. Except in very fine weather, it will be found that as the distance to which your test extends increases, more and more current passes out to line from the testing battery, because of the leakage at the supports; and if the daily testing of the

wire for insulation (earth) has been duly registered, an approximate guess at the distance of the break may sometimes be made from the amount of earth on the wire.

342. In very fine weather, and on a very good line, the amount of return current received from the wire when a strong current is sent, and the line instantly put to earth through a galvanometer, will show if the fault be near or distant. A printing machine shows the return current readily. (150.)

343. PARTIAL DISCONNECTION.—Much greater care is required in testing for this fault.

Send a weak current on the line through the detector, and let earth be put on at each successive station as before, until two stations are found, at the nearer of which the earth makes a *great* difference, and at the more distant of which it makes a *very slight* difference, in the deflection.

As some current passes the fault in each case, so much may pass, even when the earth is put on *beyond* the fault, as to deceive the tester, if a strong current be used.

When a wire is broken, and lies on the ground, it occasionally, though rarely, tests as if partially disconnected, the soil conducting the current over the break.

344. When a wire gives more resistance than it should do, there is probably a faulty joint, which should be made good.

When the section in which the fault lies has been found, the joints can be tested without interfering with messages, by connecting a wire to each side of the joint, and placing a single cell and a vertical detector in circuit between them, so as to send a current through the joint. The apparatus must be *insulated* by being placed on a tripod or a staff, and the wires may be attached by two rods furnished with spring hooks to clasp the line-wire; care must of course be taken that the line-wire is clean, and the hooks may be roughened that they may scrape it.

It is evident that when two wires are interrupted, but in different sections, the good portions of each may be connected

together, and the defective portions disconnected, so as to form one good wire out of the two bad ones.

345. INTERMITTENT FAULTS.—When an intermittent fault does not continue long enough to be tested for, let the faulty wire be *crossed* at your station, and at another, with a good wire, thus :—

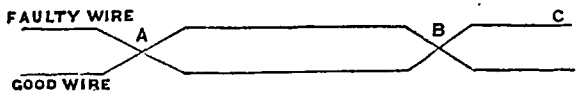


FIG. 78.

If the fault shifts to the other circuit, it will lie between A and B, the stations at which the wires are crossed.

If it remains on the same circuit as before, it is beyond B.

Let the wires be *crossed* at C, and *put straight* at B, and so on, station by station, till the fault shifts, when it will be found between the two stations at which the wires were last crossed.

To *cross* wires means to interchange them, as shown in the above diagram.

To *put* wires *straight* is to restore them to their original places.

346. TESTING AT AN INTERMEDIATE STATION.—When it is required to test from an intermediate station, the first step is to put the earth on, first on one side the apparatus, then on the other, in order to find which section is defective. So long as the earth is on, the station is, in fact, terminal, and the previous rules apply.

347. When the section of the line in which the fault lies has been determined by one of the preceding methods, it can generally be found by the line-man. But should it not be visible, it must be tested for on the line; thus :—

348. To test for earth :

Let an inspector put a current on at the station, and walk out on the line with a galvanometer, after having disconnected the wire at the other end. Let the detector be placed between wire

and earth; if the current passes, the fault will be still farther distant. This test must be repeated at different points until the current ceases, or greatly diminishes. If the weather and the insulation be bad, allowance must be made for the gradual weakening of the current, caused by the leakage at the posts.

When the fault is passed, the current will either cease altogether or be very much weakened.

If the galvanometer offers but a slight resistance, sufficient current may pass by it to deflect the needle, even after the fault has been passed. It is desirable, therefore, to make the resistance of the detector greater than that of the line to be tested.

Or the inspector may take a small battery on the line, after having insulated the section at both ends; he can then disconnect at any convenient place, and test both ways.

349. Disconnection may be tested for in a similar way, by putting earth on at both ends of the wire, instead of disconnecting it; or a current may be put on at the station and sought for with a detector, as in the previous case, taking the precaution to insulate the distant end of the wire, lest another station interfere with the tests.

The inspector may arrange with the clerk in charge of a station to disconnect, to put earth on, or to make a test at a certain fixed time.

350. When a fault is reported to exist on *both sides* of a station, it is almost always at the station itself, generally in the leading-in wires.

351. Testing for the Distance of Faults.—The principle upon which the different methods of *distance testing* are founded, is the finding the resistance of the line-wire between the testing station and the fault, by means of the Wheatstone's balance, or the differential galvanometer, and the resistance coils.

To find the distance of an earth.—The *loop test* is the most accurate, and should always be adopted whenever a second wire is available, because it is not affected by a variation in the

resistance of the fault. Shorten the length to be tested as much as possible, and let all the instruments in circuit be taken out. Choose a good wire, one free from fault, and similar, if possible, to the wire to be tested. Insulate both from earth at the nearest available point beyond the fault, and connect them together there in a loop.

352. When the *differential* galvanometer is used, the connections are made thus:—Let A B be the perfect wire, and O B the faulty one, connected together at B, the fault being an earth at F.

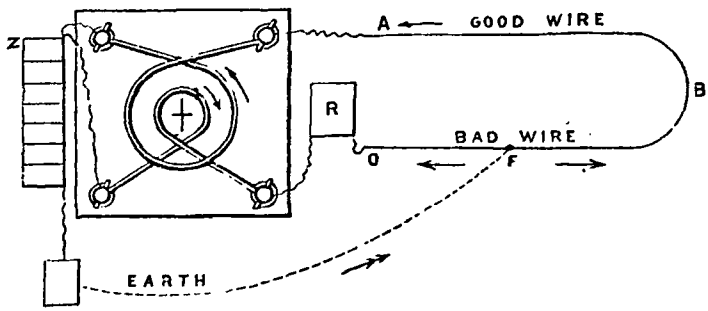


FIG. 79.

Put the copper pole of the battery to earth.

Connect the zinc to the terminal of one of the coils of the differential, and also to the opposite terminal of the other coil, by short and thick wire.

Connect the perfect wire A B to the unoccupied terminal of one of the coils.

The current will enter the wire by the fault, through the earth, and will move the needle.

Place the resistance coils R between the faulty wire and the remaining terminal of the differential: the current will now divide at the fault F; and as the distance and resistance between O and F is less than that between A and F, the current in O F will overcome that in A B F, and move the needle in the opposite direction. Resistance must be added to O F at R, until

the needle no longer moves when contact is made and broken repeatedly with the battery wire Z. The resistance R O F will now be equal to A B F. Note this resistance, and, if the resistance of the wire when perfect be not previously known, find it thus:—

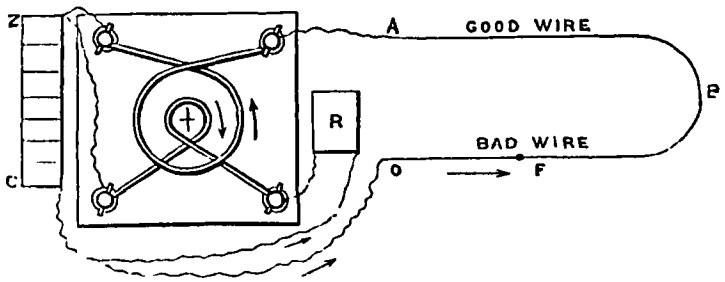


FIG. 80.

Take off the earth, connect one end of the loop to one pole of the battery, the other end to one wire of the differential. Connect the same pole of the battery to the resistance coils, the other end of the coils to the opposite end of the other wire of the differential, and the other pole of the battery to both the unoccupied terminals of the galvanometer. Add resistance till the needle is balanced; the amount added will be the resistance of the loop.

Then this resistance, less the resistance added to the faulty wire to balance the needle, and divided by two, is the resistance of the piece O F.

Thus, supposing the resistance of the loop to be 1,000 ohms, and that 100 ohms have been added to the faulty wire to balance the needle,

Then $\frac{1,000 - 100}{2} = 450$ ohms, the resistance of the faulty wire between the galvanometer and the fault.

Let A B F $= x$, O F $= y$,

Then $x + y =$ L, the resistance of the loop.

And as $R + y = x$, or $R + O F = A B F$,

$$\text{Therefore } y = \frac{L - R}{2}.$$

Say that the loop of 1,000 ohms measures 120 miles; then by proportion,

If 1,000 ohms equal 120 miles, 450 ohms will equal 54 miles.

$$\frac{120 \times 450}{1{,}000} = 54.$$

If the circuit include a tunnel or an instrument, allowance must be made for their resistance.

No two samples of iron or copper wire agree exactly in conducting power, or even in gauge; the resistance of each part of the circuit should therefore be ascertained if possible from the periodical resistance tests; but if there are no better data, the resistance of a mile of No. 8 wire may be taken as 13·5 ohms' No. 4 as 7·8 ohms, No. 11 as 23 ohms, and a mile of tunnel or other percha wire may roughly be taken as having double the resistance of the same length of No. 8 iron wire.

353. In testing short lengths of covered wire, as in tunnels, if there is no wire available for the loop in the covered work, a separate wire whose resistance has been ascertained may be used. It matters not whether its resistance be equal to that of the wire to be tested.

354. When a second wire is not available, the approximate distance of a fault may be found by testing from each of the stations at the extremities of the faulty length. But as the resistance of the fault itself is included in both tests, and may vary in the interval between the tests, the method is not as certain as the last-mentioned.

Let the wire be tested at each end in turn, while disconnected at the other; each test will give the resistance of the wire between the testing station and the fault, *plus the resistance of the fault itself*. To find the resistance of the *wire* between either

station and the fault, *add* the resistance found by the test made at that station to the resistance of the line between the stations when perfect, *deduct* the test made at the distant station, and divide the result by 2.

Thus, if A and B are the stations, a the test made by A, the wire being disconnected at B; also b the test made by B when A has disconnected, and L the resistance of the wire when in good order: $\frac{a + L - b}{2}$ will be the *resistance* between A and the fault, which can be reduced into miles by proportion, should the wire be uniform throughout; and $\frac{b + L - a}{2}$ the resistance between B and the fault.

But if a part of the line differ in resistance from the rest, as when there are tunnels, the resistance of each part must be calculated separately. For instance, suppose the open wire is No. 8, having a resistance of 13·5 ohms per mile, and that there is a tunnel a mile long, 6 miles from A, the wire of which has a resistance of 26 ohms per mile, the distance from A to B being 21 miles.

There will then be 20 miles No. 8, whose resistance is—

$$20 \times 13{\cdot}5 = 270 \text{ ohms.}$$
$$1 \text{ mile tunnel } 1 \times 26 = 26 \text{ „}$$

Resistance of the wire when perfect = 296 ohms.

Let the test $a = 300$ ohms, $b = 300$ ohms also.

Then the resistance between A and the fault is $\frac{300 + 296 - 300}{2} = 148$, or in the centre as regards *resistance*.

Now the tunnel is evidently between A and the fault, so that the resistance is made up of 1 mile at 26 ohms, and the rest at 13·5 ohms.

Total resistance, 148 ohms.
Deduct tunnel, 26 „

Leaving 122 ohms of No. 8 wire, which at 13·5 to the mile will give nine miles nearly; adding the mile of tunnel makes the distance 10 miles from A.

And as the resistance of the wire is uniform in the length nearest B, $\frac{148}{13{\cdot}5} = 11$ miles nearly will be the distance from B.

This method, with care, gives very good results, and has the advantage of not requiring a second wire.

355. The following method is not so accurate as either of the former, and is not independent of the resistance of the fault.

(1.) Let the wire be *disconnected* at the first station beyond the fault; measure its resistance.

(2.) Let it be *put to earth* at the same station, again measure the resistance, which will be less than before, because there are now two roads open to the current, viz. the fault, and the wire beyond the fault.

(3.) Subtract the second resistance from the first.

(4.) Subtract the resistance when put to earth (2) from that of the wire when in good order.

(5.) Multiply these two remainders (3 and 4) together, and extract the square root of their product. Subtract this square root from the resistance when put to earth (2), and the remainder will be the resistance of the wire between the testing station and the fault.

For example: Suppose there is a partial earth on a line whose resistance, when in good order, is 280 ohms;

(1.) And that the resistance when disconnected = 400 ohms.
(2.) When put to earth . . . . . = 240 „
(3.) Difference . . . . . = 160
(4.) And the difference between 240 and 280 is = 40
(5.) The two remainders multiplied . . . . . = 6,400

The square root of 6,400 is 80 ($80 \times 80 = 6{,}400$), which, deducted from the resistance when put to earth, leaves 160 units as the resistance of the wire between the testing station and the fault.

When there is *dead earth*, that is a fault offering *no resistance*, the wire will test precisely the same whether disconnected or not, and its resistance will give the distance of the fault at once.

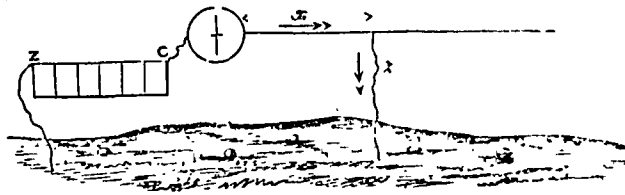


FIG. 81.

When the wire is *disconnected* at the distant end, the current which leaves the battery will go to earth at the fault, and the resistance (r) of the circuit will be that of the wire (x) between the galvanometer and the fault, added to that of the fault itself (z);

Therefore $r = x + z$.

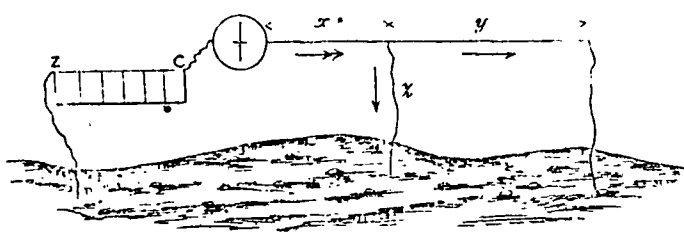


FIG. 82.

When the wire is *to earth* at the distant end the current will "split" at the fault, and will divide itself between the fault and the wire beyond the fault. The resistance (r') of the circuit will be that of the wire (x) between the galvanometer and the fault, and the joint resistance of the fault (z) and the wire (y) beyond the fault, or $r' = x + \frac{yz}{y+z}$

And when the wire is in good order, its resistance (L) is, of course, that of its two parts, x and y.

Then $r = x + z$. $\qquad L = x + y$.

$$r' = x + \frac{y\,z}{y+z}. \qquad x = r' - \sqrt{(r-r').(L-r')}.$$

356. To find the distance of a contact.—The two wires in contact will be of course *looped* at the point of contact, provided they are clean and are so twisted that the junction offers no resistance. If the contact appears to be perfect, disconnect both at the nearest point and test the two as a loop for resistance; half this resistance will then be the resistance of the wire between the galvanometer and the fault, and from it the distance can be calculated in the manner already explained.

But it is seldom that a metallic contact is perfect, nor can it be known with certainty whether the junction of the two wires offers resistance or not. It is better, therefore, to treat the fault as an *earth*, and to test one of the wires, or both in turn, by the loop test, using a third wire for the loop, or if there be no third wire, testing from each end. The wire tested will, of course, make earth through the other wire with which it is in contact: this should not be disconnected at either end, so that the resistance of the fault may be as small as possible.

357. Or the distance may be found thus:—Suppose two wires, A and B, touch one another at a point F. Let A be connected to the zinc of the testing battery, and be disconnected at the distant end; it will then serve as a battery wire between the battery and the fault (F). Let B be put to earth at the distant end, and be connected to one coil of a differential galvanometer at the testing station. Let the second coil of the galvanometer be put to earth.

The current flowing along the battery wire A will divide at F, one portion passing forward to earth at the distant end of B, and reaching the galvanometer through that coil which is connected to earth; the other part will return to the galvanometer through

the *nearer* portion of B. If the fault is exactly in the centre of B, the galvanometer needle will not move, as the currents in the coils will balance one another; but if one section of B be longer than the other, the resistance which it may be necessary to add to the shorter section to balance the needle will indicate by how much its resistance is less than that of the longer section. Let L be the total resistance, x that of the shorter portion, $L - x$ that of the longer, and R the resistance added to the shorter;

$$\text{Then } x = \frac{L - R}{2}.$$

Or add the resistance placed in the shorter section to the total resistance of the wire, and divide by 2.

TECHNICAL TERMS IN COMMON USE.

Line.—The wire connecting one station with another.

To shackle a wire.—To cut it and place an insulator between the ends.

To disconnect or cut a wire.—To take a wire off its terminal so as to break the circuit, leaving the wire insulated.

To connect up, or join up, a wire.—To replace a wire which has been disconnected.

To loop two wires.—To disconnect them from their ordinary places, and join them together, thus forming a circuit entirely metallic, so that a current sent from a station on one wire, may return to it by the other, and not by the earth.

To cross wires.—To interchange them as shown by Fig 78, page 180. In that diagram the two wires are *crossed* both at station A and station B.

Changes are made at the testing-box and not at the instrument.

A service message to cross two wires, should simply state the numbers or names of the wires to be crossed; and the reply to any service message requiring an alteration of the wires, should state exactly what has been done, thus:—

Message: "Cross Nos. 1 and 2."—*Reply:* "Nos. 1 and 2 crossed."

To put wires straight.—To restore the *ordinary* arrangement of the wires, or instruments.

To put to earth.—To connect the line-wire or instrument to the earth-wire.

Circuit.—The wires, instruments, &c. forming the path for the passage of the current.

Metallic circuit.—When a return wire is used instead of the earth.

To short circuit a battery.—To connect its poles or end-plates by a piece of wire.

To short circuit an instrument.—To connect the line and earth terminals by a piece of wire.

Local relay circuit.—One which includes only the apparatus in the office, and is closed by a relay actuated by the line current.

Local battery.—The battery of a local relay circuit.

Terminals.—The screws of instruments, batteries, or test-boxes, to which the wires are connected.

Shunt.—A wire connected across the terminals of a coil, so as to divert a portion of the current.

Reverse current.—A current in an opposite direction to that used for producing a signal, or mark.

To reverse a current.—To change its direction.

To reverse a battery.—To interchange the wires leading to the instrument, to turn the battery end for end.

Deflection.—The movement of the needle of a galvanometer or the angle through which it moves.

Full deflection.—When a needle is deflected to the full extent of its scale.

Deflections.—This term has been used to indicate the spontaneous currents in wires, which appear to be caused by currents flowing from one part of the earth to another. It is better to call them "earth currents."

To take the constant of a galvanometer.—To ascertain what deflection the battery used for testing would give upon the galvanometer through a certain fixed or *constant* resistance, such as the so-called *standard resistance coil* (306).

Modes of connecting the wires for testing.—To test the battery and galvanometer on the standard coil, or to take the *constant* of the galvanometer. (That is, to find what deflection it gives with one cell through a given resistance R.)

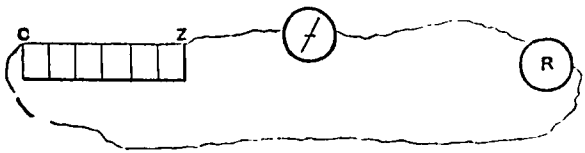


FIG. 83.

For insulation or earth, or to send a current on the line:—

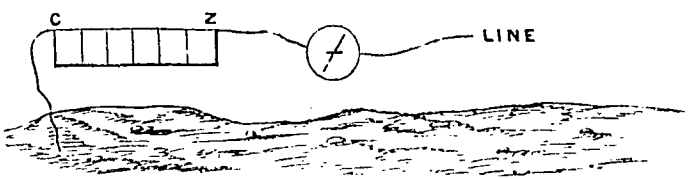


FIG. 84.

For contact between two wires:—

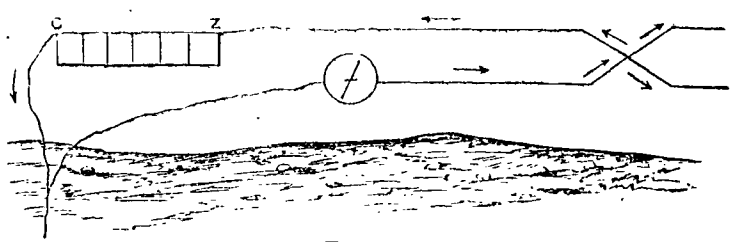


FIG. 85.

To receive a current from another station:—

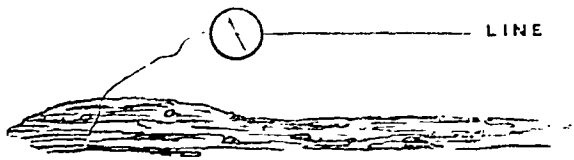


FIG. 86.

Copper always to earth. Zinc to line.

PART IX.

INSTRUMENTS FOR SIGNALLING.

NON-RECORDING INSTRUMENTS.

358. THE NEEDLE.—The needle instrument is simply a vertical galvanometer (120), with a key or apparatus for placing a battery in circuit, and for reversing the current.

The lower end of the inside needle is a north pole, and the coils are wound so that if the copper of a battery be connected to the left, and the zinc to the right-hand terminal, the top of the needle will move to the right.

359. When several instruments are connected in circuit, the wire connected to the right hand of the coil in the first must be joined to the left hand of the coil in the second, and so on, so that the current may flow always in the same direction, for the direction of the movement of the needles depends on the direction of the current (116).

Take three instruments, 1, 2, and 3. If the left side of the coil 1 be connected to the earth, and the right to the line wire leading to 2, then, to make the current traverse the coil 2 in the same direction, it must enter at the left and leave by the right, and the line wire coming in from 2 must be connected to the left side of the coil at 3, which, being the terminal station, must have the right side of its coil connected to the earth.

Thus, the *up* station earth and all the *up* wires are connected

to the *left*, the *down* station earth and all the *down* wires to the *right*, and *vice versâ*.

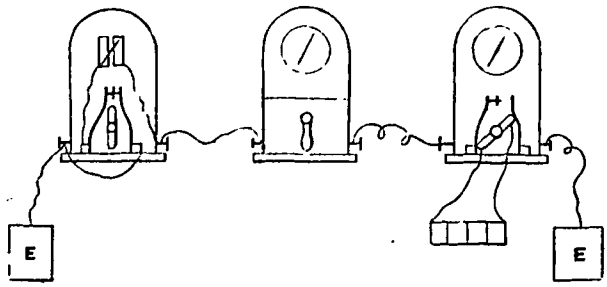


FIG. 87.

The principle is the same however the instrument may be arranged.

In fixing double-needle instruments the practical rules are:—

Connect the instrument so that when on short circuit (*i.e.* when the two line terminals are connected by a short wire) the needles move in the same direction as the handles.

After connecting up an additional instrument on a double-needle circuit, give the test signals + E H N slowly, making a long pause after N, to separate each group of signals, and to show when the group is commenced. If a single needle, give E T in a similar manner, until some station sees the signals and repeats them.

If they are not repeated correctly, your wires are wrongly connected, and must be altered until the signals are received accurately on your own dial. If you receive E + N H, both your needles are wrongly connected, and the line and earth wires must be reversed; if + E N H, the + E wires are correct, and the H N reversed, and so on.

Whenever unintelligible signals are received, the test signals should always be given, in order that the distant station may have a chance of communicating by altering its wires, or that you may see what is wrong, and alter your own wires so as give any necessary instructions.

If, after connecting two instruments according to the previous instructions, the needles move in opposite directions, either the coils of one have been wound in a reverse direction or the polarity of one of the needles has been changed.

360. If the line wires of one of the instruments are reversed, the signals *received* at that station will be reversed also; *forwarded* signals will be read correctly on its own dial, but will be reversed at other stations. If the battery wires are reversed and the line wires correctly connected, signals will be *received* correctly at the station; but those *forwarded* by it will be *reversed*, and the needles on its dial will move in the opposite direction to the handles. If both line and batteries are wrongly connected, received signals will be reversed, but other stations will be able to read, because the effect of reversing the line is counteracted by the reversal of the batteries. The needle will still move in an opposite direction to the handles. It is evident that no alteration of the battery wires can affect *received* signals.

361. The faults to which the needle instrument is subject are:—

(1.) Demagnetization by lightning, or the absence of what is called retentive power in the needle, causing the signals to become weak or to cease altogether.

(2.) Reversal, when the poles of the needle are changed by lightning, and the signals appear reversed, as if the batteries were wrongly connected. In both these cases the needle must be re-magnetized (106), and in effecting this care must be taken not to bend the pivots.

(3.) When the needle can be moved in one direction only, one pole of the battery at the station has become permanently connected to the earth, from damp in the battery room, accidental contact of a battery wire or plate with the earth, or a contact between one of the battery connections inside the instrument and the earth or line, caused by metal dust worn from the pins or bearings, dirt and oil, or pieces of coil wire broken

off. In the case of earth on the battery wire or battery, the needle can be moved one way when the faulty battery wire is disconnected from the instrument. If the needle can be moved when *either* battery wire is off, both wires make earth.

(4.) One station is able to speak to all the rest, but no other station can give a signal. This fault will be found at the station which is able to work, and is caused by the circuit being broken by dirt on the points on which the line-springs rest. Moving the handle or lever of the faulty instrument removes the spring from the points on which it rests, and completes the circuit through the battery, so that signals can be *sent;* but in order to *receive,* the circuit must be re-established at the points. The dirt prevents this. A case has occurred in which communication was restored by burning up this dirt by a powerful current sent on the line from another station.

(5.) Signals are uncertain: they sometimes miss. A battery plate is defective; or a connection is loose, and the jar caused by moving the handle breaks the circuit: the battery pins, or the springs or blocks on which they rub, are dirty or rusty. When one side of the battery pin is dirty and the other clean, the needle can only be moved one way. In a double-needle instrument, if one needle only is faulty, the defect will, of course, not be in the battery, but in the instrument connections. *Bad oil frequently causes this class of faults.*

(6.) Signals can only be made by moving the handle as gently as possible, and, when made, fail if a little extra pressure is used. The cause is a defective connection, which is broken by the extra pressure.

The fault is readily found by holding the handle in such a manner as to cause the signals to fail—that is, so as to break the circuit—and connecting the points of contact, one by one, by a knife or a bent wire, until a part is found on touching which the needle moves, showing that the fault has been bridged over (327).

(7.) The needle sticks to the ivory pins. Wipe them carefully with a dry handkerchief, or rub the edge of the needle with a black-lead pencil. The needle is not free to move in the coils, or the pivots are too tight or bent; examine them, and make the necessary adjustments.

(8.) The needle moves in an opposite direction to that of the handle of the instrument. The batteries may be reversed; the needle reversed by lightning; or the coil wires crossed.

Examine the battery wires and the coils; see if the N. pole of your magnet repels the lower end of the needle, as it ought to do.

(9.) Sometimes one of the spiral springs which secures the connection of the battery with the barrel is bent, so that when the handle is moved it connects one pole of the battery to the line or earth, and thus puts it on short circuit.

(10.) Contact, generally intermittent, between the two needles of a double-needle. If not on the line, the cause may be this: the inner ends of the coil wires are soldered to the metal of the coil frames, so that when the two half coils are placed in the slide, the coil wire is connected with it and with its dial. Thus if anything occur *to form a connection between the two dials*, which are ordinarily insulated, the wires of the two coils will be in contact, and the current will divide between them.

This sometimes happens through the metal face of the case of the instrument, if the ivory pegs placed in the dials are worn away, or if the case is warped so as to press the face upon the dials.

(11.) At railway stations persons sometimes place books and parcels under the instruments; occasionally a key or other conductor will be laid so as to touch both the bolts which screw down the "works" of the instrument, causing intermittent contact.

(12.) Cross or "crooked" handles; causing an occasional disconnection in one of the wires, and sometimes a contact.

If the interruption ceases when one particular station works, call that station if possible; if not, call every station you can, and ask each to look at his handles. If a barrel is stiff in its bearings, these faults frequently occur. Too great care cannot be taken to make them work freely, and to prevent wear by careful oiling with *best salad oil*, not lamp oil. When the barrel of the instrument has two bearings, the handles are very apt to become stiff from the warping of the wood. (See method of finding cross contact.)

(13.) Wire broken inside percha, especially when the instrument is not screwed down.

(14.) Wires connected, when two or more are fixed down by a staple, which cuts through the percha.

(15.) Coils fused by lightning, or coil wire broken. In this case the needle will not move on short circuit, or when the line terminals are connected by a wire, even after it has been re-magnetized.

If there are no spare coils to replace those which are damaged, the following temporary expedients may be adopted:—If one half the coil is defective, remove it, and connect the terminal to which its wire was fixed to the bar on which the coils slide, leaving the remaining half in circuit. If both halves are useless, take one-half of the other pair of coils, completing the circuit, as in the former case, by connecting the terminals left vacant to their respective frames. The signals will be weak, but readable. If both sets are damaged, connect the coil terminals across, so as to enable the rest of the circuit to be used.

(16.) Cross contact on double-needle.

When the wires of a double-needle are in contact, if one of the handles of an instrument be moved it will make Q or Z on the sender's dial, and either Q Z or R W on the other dials in circuit.

Suppose the handle be moved, as if to make E, the current will pass along the + E wire to the place of contact, and will divide

there among all the channels open to it; part will continue along the wire on which it was sent, part will pass into the H N wire, and flow along it to the earth at each end, part will travel back through the sending station to earth, and part through the stations beyond the fault to earth. The current in the H N wire will travel in the *same direction* as in the + E to the earth beyond the fault, and in a *reverse direction* to the earth on the same side as the sending station. Thus the needles of all stations on the same side of the fault as the sending station, will move in *reverse* directions, and those beyond the fault in *parallel* directions.

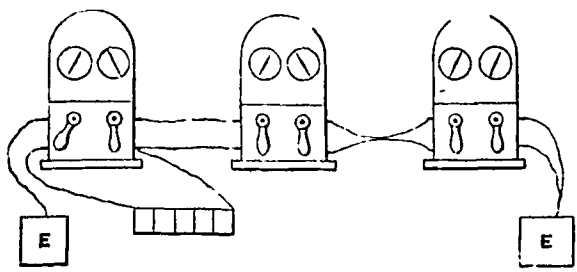


FIG. 88.

By calling the several stations, and getting them to give + E H N, you may find with certainty between which two the fault lies. Call the middle station: if you receive Z Q Z Q, the fault is beyond it. Call the other stations beyond in succession until you find one which gives W R W R. This station is on the opposite side of the fault to those giving Z Q Z Q.

There is but one exception: when every station gives Z Q Z Q for + E H N, the earth is defective at one of the terminal stations.

The commutator or handle of the needle instrument has lately been replaced by a pair of lever keys, in order to assimilate its manipulation to that of the "Bell" instrument. The contacts are possibly not quite so sure as those of the older form.

The greatest improvement which has been made in the needle

instrument is the introduction of an induced magnet of soft iron for the needle, in place of the permanent steel magnet. The iron needle is pivoted so as to lie as close as possible to a permanent magnet, at least four inches long, without touching. The permanent magnet, being somewhat large and lying outside the coil, is not affected by atmospheric electricity.

The double-needle instrument has considerably gone out of use since this work was written, but still the foregoing and other paragraphs relating to it will not be without value.

ACOUSTIC TELEGRAPHS.

362. The Morse signals can be read by sound. In America and India the paper is dispensed with, and the sound caused by the armature is increased by special contrivances. The *record*, which experience has proved to be a great safeguard against error, is thus lost, but the system is convenient and economical. It has, moreover, the great advantage that the attention of the clerk need not be so closely applied in watching, as the *call* can be heard, even at a distance; and the message can be written as from dictation, without looking at the instrument.

There are two kinds of acoustic instruments, the *sounder*, as used in America, which is simply an electro-magnet with an armature fixed to a lever, a Morse without the style and clock-work; and the *bell*, used to some extent in England, which is really but two such sounders, differing in tone. The first gives the long and short strokes of the Morse alphabet, the last the right and left beats of the needle instrument, or the dots in two lines of the modified Morse; and they are worked by the keys suited to those instruments.

The *bell* is far more rapid than the *sounder;* as far as the speed of manipulation is concerned, it is the most rapid of all non-

automatic instruments; but the *sounder* can be read as fast, if not faster, than the writer can follow: hence much of the advantage of the bell disappears. Moreover, the bell, being really a double sounder, requires double the care in adjustment, and the electrical difficulties connected with it are, as in the case of the modified Morse, which will presently be described, much increased especially by the impossibility of employing the system of reversed currents.

On a good line the advantages of the bell show themselves; but the sounder being, like the Morse, capable of being worked by double current, can be readily kept in action upon a wire on which the bell would fail.

It should be understood that the *bell*, so called, is really merely a plate of metal upon which the armature lever strikes: the sounds must be *dead*, not ringing.

The signals are frequently read from the sound made by the armature of the Morse apparatus, the paper ribbon being referred to only in case of uncertain signals, or retained for future reference.

One great merit of the sounder is the excessive simplicity of its mechanism, rendering it very easy to be maintained in working order, a point of great consideration in countries like India, where skilled labour is scarce.

RECORDING TELEGRAPHS.

363. A *recording telegraph* is one which records its own signals, either in ordinary letters, or in a special or conventional alphabet of dots, or dots and dashes.

The simplest alphabet is that of Professor Morse, of the United States, which consists of dots and dashes. It has been altered from time to time, in order that accidental irregularities

in the distance between the dots and dashes shall not transform one important word into another; and although we at one time possessed an alphabet better suited to our own language than that now used, it was found necessary, on the establishment of direct communication with continental cities, to fall in with the system in use abroad, and the same characters are now employed throughout the whole of Europe, Asia, and Australia.

364. THE BAIN SYSTEM.—In this telegraph the Morse signals are produced by chemical decomposition. When a current is caused to pass through the solution of a chemical compound, it decomposes it or separates its component parts; in many cases producing an alteration in colour, either by causing the wire which conveys the current to be dissolved, or by separating a coloured solid substance from a solution previously colourless. Thus if a current be made to pass through paper soaked in iodide of potassium, iodine will be separated at the wire connected to the copper of the battery, and a brown stain will be produced.

It is more convenient to employ a mixture of equal parts of saturated solutions of ferrocyanide of potassium and nitrate of ammonia, diluted with an equal volume of water—one part of each solution to two parts of water.

Place a sufficient quantity of good nitric acid in a wide pan of glass or stoneware, and throw into it lumps of ordinary carbonate of ammonia until it ceases to effervesce, taking care not to put in so much at once as will render the effervescence violent, and that enough is added to leave a small portion undissolved after the acid is saturated, for it is necessary to have a little free ammonia (*i.e.* ammonia not combined with nitric acid) in the liquid. This liquid will be a saturated solution of nitrate of ammonia, with free carbonate of ammonia.[1]

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[1] The following formula has been given. To each pint of a perfectly neutral and saturated solution of nitrate of ammonia, add one dram of carbonate of potass.

The saturated solution of ferrocyanide of potassium is made by dissolving as much of that substance as the water will take up.

It is better to mix only as much as will last two or three days, for *mixed* solution decomposes. The prepared paper should be preserved in a covered jar, in order that it may not become dry, and it must not be used too moist; it should always be prepared five or six hours before it is wanted for use.

Nitrate of lime can be used instead of nitrate of ammonia; it is made in a similar way and is very much cheaper, but does not answer quite as well.

The principle of the invention may be elegantly shown in the following manner:—Soak a sheet of printing paper in the mixed solution, blot it off, and lay it smoothly on a plate of zinc or sheet of tinfoil connected with the zinc of a Daniell battery of twenty cells. Connect a steel pen, fixed in a wooden holder, with the copper of the battery by means of a flexible copper wire. The pen will now be found capable of writing in blue upon the prepared paper; but if either wire be disconnected from the battery the pen will cease to mark, the power to do so being entirely dependent upon the passage of the current.

In Bain's telegraph, a ribbon of moistened paper is carried forward by clockwork over a metallic roller, thus—

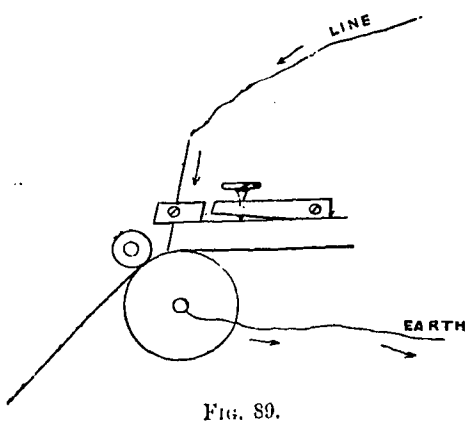


Fig. 89.

and is made to pass under a pencil of iron wire, connected to the line wire, or to a relay, in such a manner that the positive or copper current passes *from the wire to the paper*, and through the paper to the metallic wheel of the apparatus which moves it forward.

When a current is sent on the wire, the solution with which the paper is soaked is decomposed, combining with the iron pencil to form Prussian blue, and making a blue mark on the paper.

On short lines the *line current* (current from the sending station) is sufficiently powerful to decompose the solution, but on long lines it is necessary to employ a local current from a relay. The local battery should consist of 18 or 24 cells of an ordinary line battery.

Care must be taken to keep the wheel over which the paper runs quite clean, or the current will not pass freely.

All pieces of metal exposed to the action of the paper or solution should be tinned, as the liquid has no action on tin, while it rapidly dissolves copper or brass. A little dilute ammonia readily dissolves the compound of copper which is formed.

365. The Bain apparatus is very useful for experimental purposes, as two or more separately insulated pencils may be placed side by side upon the ribbon. It may be used as a chronograph for ascertaining the speed of transmission of signals, by connecting one pencil with the pendulum of a clock beating seconds, so as to mark a dot upon a ribbon each second; and another pencil with the line wire. The signals will then be registered parallel with a scale of seconds, so that the time occupied by each and the number received in a given period can readily be ascertained. The speed of the machine will be sufficiently uniform during each second.

When it would be inconvenient that the marking pen should dissolve away, platinum wire is used instead of iron, and the paper is prepared with a solution of nitrate of manganese.

366. The MORSE INSTRUMENT consists of a key for sending the current, and an electro-magnet, the armature of which is fixed to a lever carrying a point or style, which embosses a mark upon a band of paper carried forward by wheelwork. The electro-magnet attracts its armature as long as a current is made to flow through the wire with which it is wound, and ceases to attract it as soon as the current is cut off by breaking battery contact with the key; the armature is then drawn back by a spring. The paper is carried forward by two rollers, in the uppermost of which there is a groove to receive the point of the style.

367. Digney's *ink-writer*, as manufactured by Siemens, is a great improvement upon the original Morse instrument. A small thin disc is fixed upon the armature lever, and is driven by the clockwork in a direction contrary to that of the paper ribbon. The disc dips into a trough filled with an ink, made by diluting good printer's ink with olive oil, from which the stearine has been removed by freezing; and when raised into contact with the paper, by the action of the electro-magnet, writes the signs in colour upon it. The embossed marks can only be read in a certain light; the written signs are as legible as can be desired; the apparatus is capable of being worked by a much feebler current, and requires but little more care, than the Morse.

368. The duration of the current and length of the mark in both instruments depend upon the duration of the contact made by the *sending-key*. This key, in its simplest form, is merely a lever attached to the line wire, which, when at rest, connects the wire with the apparatus for receiving signals; but when pressed, places a battery between the wire and the earth, so as to send a current to the distant station. This is called a *single current* key. On long lines especially, and where there are many instruments in circuit, there is considerable advantage in using what is called a *double current* key (376), which reverses the current after each signal.

369. For distances under forty miles, an ink-writer, or with

good insulation even an embossing Morse, may be worked by the line current itself. The connections are made thus, P being a lightning protector formed by twisting the two line wires together (180) :—

For longer distances an *ink-writer*, wound with No. 35 wire, is necessary, for the line current may be powerful enough to mark the paper when it is too feeble to indent it. The distance to which this instrument will work depends mainly upon the insulation of the line wire, especially upon its freedom from contact: 120 miles have been worked satisfactorily in all weathers on a *direct* wire where there are no intermediate instruments.

370. The attraction of the electro-magnet for the armature decreases very rapidly as the distance between them increases; therefore, the weaker the current the nearer must the armature be allowed to remain to the magnet when at rest. This adjustment is made by the screw which limits the distance between the magnet and the armature. The spring which draws the armature from the magnet provides a second adjustment to suit the varying strength of the current.

Where there are several instruments in circuit the adjustment for current becomes difficult, as it is hardly possible so to arrange as that the strength of the signals from each station shall be uniform, and it is better to use a relay (373), which requires but a very feeble current, and is much more easily adjusted.

371. CLOSED CIRCUITS, or circuits worked by constant currents. This system is universal in the United States, and was at one time used somewhat extensively in England.

The sending keys at the several stations are so arranged that when they are at rest the circuit is complete, and a constant current flows through the whole of the instruments, attracting their armatures; so that, if the paper were allowed to run forward, a continuous line would be marked upon it. By opening a switch attached to the keys the circuit is broken, and the break

SINGLE CURRENT MORSE.

THREE STATIONS WORKING BY LINE CURRENT.

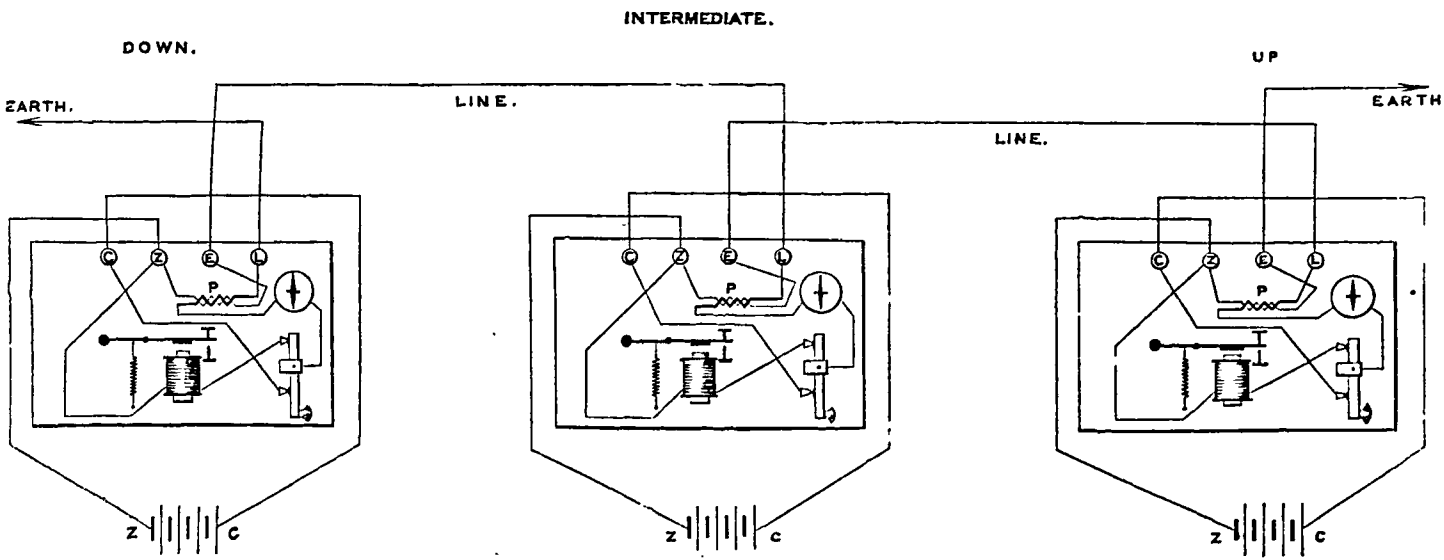


FIG. 90.

or gap thus made can be again filled up by pressing the key. Thus, if any station opens its switch the current ceases, and all the armatures are released; if this same station presses its key the circuit is again closed, and the armatures are attracted so as to produce signals.

There are several objections to the system of constant currents. It rapidly destroys buried wires, if they are at all defective in insulation. It answers well when there are but two stations; but causes which affect the insulation of a line of open wires are more felt than under the ordinary system, where batteries are placed at every station, causing the current to be extremely irregular. The system has been abandoned at home except in special cases, notwithstanding the great economy and convenience with respect to batteries.

The best position for the batteries is one-half at each terminal station; for if they are all placed at one station a fault on the line will obviously have a greater effect upon the working of the circuit than when they are divided.

The relay may be used with advantage here also.

Notes as to the Adjustment of the Ink-writer when worked by Line Current.

372. (*a*) First adjust the screw which limits the approach of the armature to the electro-magnet, so that the upper edge of the inking disc shall gently touch the paper when the armature is attracted, while the lower part of the disc deposits the ink. If the disc presses the paper too hard, it makes thick and indistinct signals: if it presses too light it causes the disc to jump and signals to split: thus —— may become - — or — —.

(*b*) Raise the electro-magnet by its adjusting screw, so that when the armature is attracted only a slim streak of light can be seen between the electro-magnet and the armature.

(*c*) Adjust the screw which limits the upward motion of the armature so that it may be free to move through a space of about a sixteenth of an inch.

(*d*) Adjust the tension of the spiral spring which acts in opposition to the force of the current so as to bring back the armature to its position of rest when the current ceases to act, and to overcome the effects of *residual magnetism*, if any exist. The amount of tension required will vary with each instrument. The letter V generally should be sent by the distant station, using very low power, and the spring gently tightened until the marks are clear and distinct. The ear is usually the best judge of this adjustment.

The instrument is now regulated to work with the most delicate currents.

(*e*) The adjustment for the stronger current of a nearer station is made by lowering the electro-magnet, and, if absolutely necessary, tightening the spring.

373. RELAYS.—The *relay* is an apparatus capable of being actuated by a feebler current than that required for a signalling instrument; it is as it were an automatic *key* which is set in motion by the line current, which by closing a circuit composed of the Morse or other signalling instrument and a local battery, causes a stronger current to act on the apparatus than can be afforded by the line wire. In whatever manner the *relay* may be constructed, its principle is the same. It consists of a bar either of soft iron or of magnetized steel, fixed so as to be free to move when acted on by an electro-magnet or coil.

The wire of the electro-magnet or coil M M (Fig. 91) is placed in the line circuit; the bar is connected with one pole of the local battery L; a pin or stop, fixed near the bar, is connected to one end of the Morse machine coil, and the other end of this coil to the other pole of the local battery.

When no current is passing on the line, the bar is held away from the stop by a spring or other means; but when a current

is sent on the line, the bar moves towards and touches the stop, so as to *complete a local circuit* composed of the printing machine and a battery. Immediately the current ceases in the line wire, the bar flies back and opens the *local circuit.*

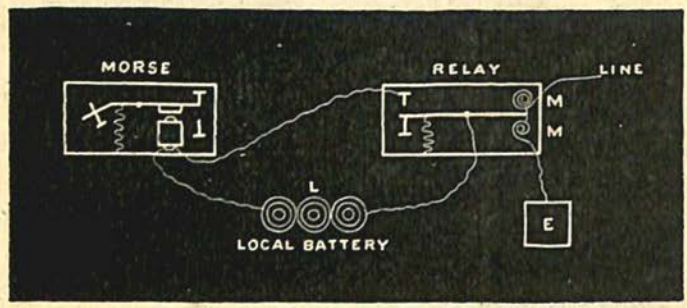


FIG. 91.

When permanently magnetized armatures or bars are used, the line current must be made to pass in one and the same direction through the coils of each relay in the circuit, and the same rules must be observed as in connecting up a series of needle instruments (359). But when the armature is soft iron unpolarized (which is seldom the case), it matters not in which direction the current passes through the coils. In the latter case the armature is always attracted, while in the former the direction of its motion depends upon the direction of the current.

374. In Fig. 92 the larger battery z c is the line battery; the smaller, marked "local," is the local battery or the battery which is brought into action by the relay 5, 6. The galvanometer 2, 1, is for the purpose of showing whether the current passes; 3, 4, is the single current key, and the Morse is shown at the left of the key.

The numerals indicate the direction of the current: for instance, if the key at the "up" station is depressed, the positive current of the line battery flows to the key at 3, enters the galvanometer at 2, leaves it at 1, passes along the line to the intermediate instrument, entering its relay at 6, leaving the relay at

SINGLE CURRENT MORSE.

THREE STATIONS WORKING BY RELAY.

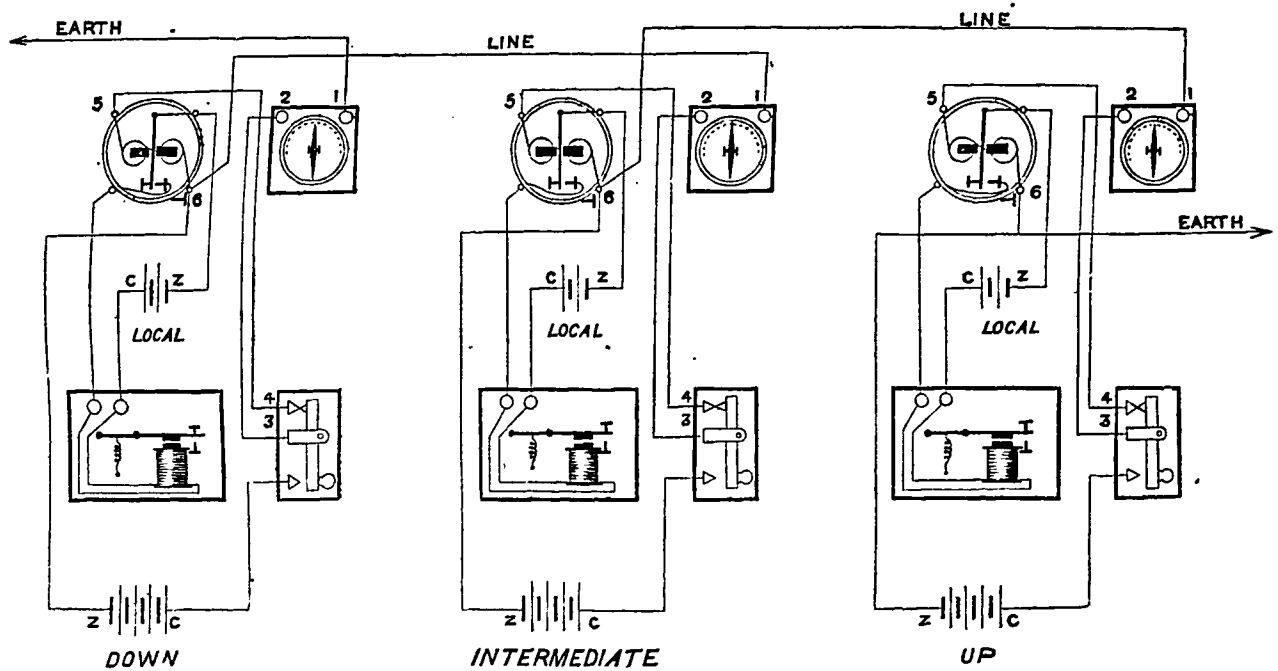


FIG. 92.

5 for the back-stop of the key 4, whence it passes to the lever of the key 3, and then through the galvanometer 2 and 1 to the line leading to the next station.

The numerals serve also to indicate the manner in which the several pieces should be connected. There are two figures on each; the lower of the two is joined to the next lowest, the higher of the two to the next highest as regards several parts at the same station; and as regards the distant stations the lowest of each group is connected to the highest of the distant group. Thus 1 of the up station is joined to 6 of the intermediate station.

If the coils of the electro-magnet are wound with a somewhat thick wire, as No. 24, a few cells, say six, will suffice for the "local," but they must be *at least* twice as large as those used for a line battery; if a thinner wire, as No. 30, be used, ten or twelve cells, similar to those of the line battery, will suffice. The line battery itself, or part of it, may *occasionally* be used as *a local;* but as these cells have very much more work to do than the rest, they become weak sooner, and require constant attention. It is therefore much better to use a separate battery, and it is far more convenient to use No. 30 wire for the coil, so that only one description or size of battery is required for the work of the office.

375. In the case of a relay consisting of an electro-magnet with a soft iron armature, the first effect of reversing the current after the armature has been attracted is to *repel* it; but almost immediately after it is *re-attracted.* For, although soft iron loses its magnetism very rapidly, yet it retains it for a short time after the current ceases, so that the armature retains the polarity impressed upon it by the electro-magnet for a moment after the poles of the electro-magnet have been reversed. So long as the armature retains this polarity it is repelled by the reverse current, but as soon as a fresh polarity is given it, it is again attracted. Thus, if the key by which the signals are sent on the line be arranged so as to give a very short reversal of the

current after each signal, the armature will be repelled, and will be prevented sticking, as it will sometimes do, especially if it be allowed to touch the core of the electro-magnet. A very much less powerful spring will then be required to break the battery contact, and therefore a less powerful current will suffice to give the signals.

376. *Double Current System.*—A still more sensitive relay may be constructed by abandoning the spring altogether, and trusting to the reversal of the current, not only for removing the bar from the battery contact, but also for holding it back during the interval between each successive signal. This is effected by the employment of a key so arranged, that during the transmission of a message the line is constantly occupied by a current; moving in the one direction to bring the relay into the position of battery contact, and in the other direction to remove it from that position and hold it back. The marking current will now have comparatively little work to do, not having to overcome the resistance of a spring.

The moveable bar or armature must be magnetized, so that the direction of its motion may be reversed by a reversal of the current in a similar manner to the needle of a galvanometer.

But another most important advantage is attained by causing the line to be constantly occupied by a current during the transmission of a message.

When the line is free in the interval between signals there is a limit to the degree of delicacy of the relay; because, if very sensitive, it will be acted on by all the small leakages from the other circuits near it, and will print false signals. But when the line is occupied by a current between the signals, there is no such limit, and an instrument delicate enough to record the leakage from other wires will yet print accurately whatever is sent on its own proper wire. Should the current leaking into the wire in the intervals between signals be in the same direction as the reversed current, it

assists in holding the bar back. Should it be in the direction of the direct or printing current, it will not move the relay unless it is powerful enough to neutralize the reversed current.

377. *Varley's double current key* consists of a divided disc furnished with a lever handle. One half of this disc is connected to the zinc, the other half to the copper pole of the battery. Springs, connected respectively to line and earth, press each upon one-half the disc. When the key is moved, the spring which had previously been in contact with the zinc touches the copper half, and *vice versâ*, so that the battery is always in circuit with the line.

This being so, it is necessary so to arrange the key that the line wire shall during the *sending* a message be disconnected from the receiving apparatus and connected to the key alone, and *vice versâ*, by means of a switch generally moved by the hand. This switch also disconnects the batteries from the key. The receiving station cannot stop the sender, or reply, until the switch has been turned from *send* to *receive*. Practically, this is not objectionable on a recording instrument, but when a *sounder* or acoustic instrument is worked by double currents, it is a great disadvantage. A special arrangement is therefore required when the sounder is worked by double currents to show whether the receiver wishes to stop the sender.

The "tell-tale" galvanometer is wound with two separate wires, one of them in the receiving circuit, the other in the battery circuit. In sending, the first is switched out of circuit, but the out-going signals pass through the second, and it is also affected by any currents passing inward from line. Thus, it is easily seen if the receiving station breaks the circuit or sends a current.

The rubbing contact made by Varley's key is a great advantage when insulation is defective, for the length of the battery contact may be adjusted to suit the state of the line. The

worse the insulation, the longer must the current be allowed to flow to line.

But in tolerably well insulated lines it is not necessary thus to prolong the contacts, and the distance through which the key must move is found seriously to diminish the speed of signalling. Double current keys are now made whose "play" is as short as that of a single current key, and their form is constantly undergoing improvement.

378. The single current key may be made to send double currents by attaching a switch to the *back-stop* (the stud on which the key lies when at rest), arranged to connect it either with the receiving apparatus, or with a second battery connected in a reverse direction to the sending battery. Thus, when the key is at rest a current flows to line, but in an opposite direction to the signalling current so long as the switch is in the position for *sending*.

These switches are frequently made automatic. The back-stop is connected to a bar which plays between two stops in the same manner as the marking lever of the Morse instrument, and is acted on by an electro-magnet similarly to the Morse itself. The lower stop is connected to the key, the upper stop to the receiving instrument and the electro-magnet in the battery circuit.

Thus, so long as a current is passing from the battery, positive or negative, the lever is drawn down so as to connect the back-stop of the key with the reversing battery.

It is necessary that the lever shall not rise too promptly, or the connection with the battery will be broken before the key touches its back-stop, and the reversal will not pass to line. The best method of effecting this is shown in the description of the double current translator. Many other plans have been used, among them a piston moving in a cylinder filled with oil, having a valve which opens as the piston descends, but closes as it rises; and a vane driven by wheelwork. The shunt is, how-

ever, the best method, as the degree of retardation can be regulated with great nicety by varying its resistance.

379. When working with reversals, if the line current is very weak, there is a great advantage in giving the bar of the relay a tendency to rest against the battery contact stop, instead of upon the insulated stop, keeping the local circuit always closed. It requires a certain force to *make* perfect contact, but very much less to *break contact;* thus, when signals are weak the current may have power enough, when reversed, just to remove the bar from the battery stop, so as to *break contact,* when it would not be able to press them sufficiently firmly together to *make contact* unless aided by the tendency given to the bar, far less to move it through the space between the stops. *Care must be taken not to leave the batteries thus on short circuit when the instrument is not in use, as it would weaken them seriously.*

380. In order to increase the power of permanently magnetized armatures, and to lessen their liability to lose their polarity, they are frequently magnetized by the *induction* of a large magnet placed in contact with or near them. Such relays are said to be *polarized.*

381. *Siemens' polarized relay* N S (Fig. 93) is a hard steel permanent magnet, whose south end S has a slit, in which the soft iron armature *a* is pivoted, so as to have a free motion from right to left. To this armature a thin tongue *b* is attached, which, by making contact at the point *c,* completes the local circuit. To the north end N of the permanent magnet the soft iron cores of the electro-magnet are fixed, as shown in the sketch. These cores are surrounded with bobbins of wire, through which the current flows. The upper ends of the electro-magnet are fitted with moveable pole-pieces *n* and *n'*, which are fixed by screws, as shown. The permanent magnet N S induces north magnetism in both the extremities *n* and *n'* of the electro-magnet, and south magnetism in that portion of the armature which plays between them. When the armature

is equidistant from the poles of the electro-magnet, it is equally attracted by each; but if it be brought nearer to one than to the other it will be held there, because it is under the influence of a more powerfully attracting force. Since the relative distance

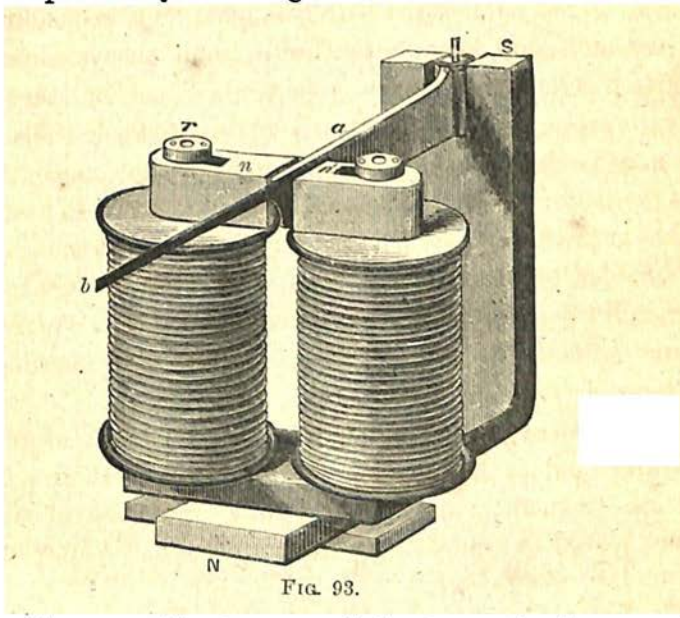


FIG. 93.

between the moveable tongue and the two pole-pieces can be increased at will, the attraction between either pole and the moveable tongue can be adjusted with great delicacy without the aid of a spring.

The electrical contacts for the local circuit are shown in Fig. 94, and the diagram is drawn with the tongue breaking the local circuit.

The adjustments are made thus:—

(*a*) The pole pieces n and n', are placed at a convenient distance apart, and by the action of the screw B the tongue b is brought, as nearly as possible, in the centre between them (so as to have equal room for adjustment on both sides). Screw A is then adjusted, so that the motion of the tongue shall be about $\frac{1}{25}$ of an inch between the insulated stud d and the contact point c.

(*b*) Screw B is next adjusted, so that when no currents flow, the armature shall be slightly attracted by the pole bringing the tongue into contact with the insulated stud *d*.

(*c*) If, after the instrument is so adjusted, the paper is marked in a continuous line when the distant station is sending, turn screw B to the right, in this way lessening the attraction of *n*, and increasing that of *n'*. If this produces no effect, either place *n* a little farther from, or *n'* a little nearer to the tongue, until the result desired is attained.

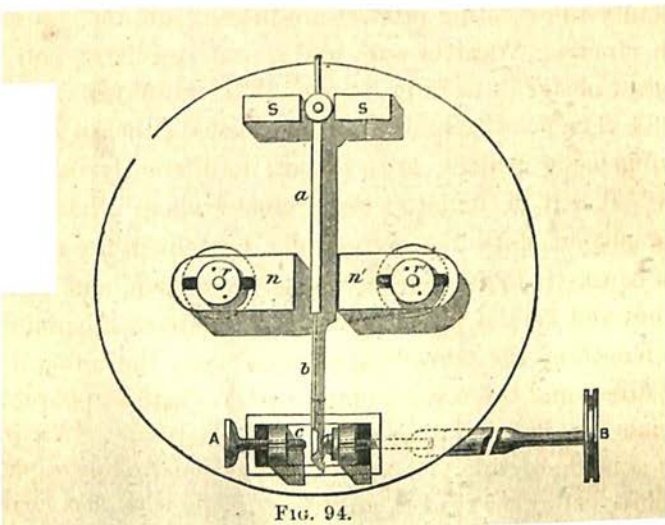


FIG. 94.

(*d*) If, on the other hand, there is a loss of dots, turn screw B to the left—thus diminishing the attraction of *n'* and increasing that of *n*. Should this not produce the desired effect, then move *n'* a little farther from, or *n* a little nearer to, the tongue.

382. *Varley's Relay* consists of a soft iron bar fixed so as to move horizontally within a hollow cylindrical coil. It is polarized by horse-shoe magnets at each end, between the poles of which the bar plays. One of the magnets is moveable, and serves to adjust the relay by attracting the bar. A thin flexible spring is fixed to the end of the bar, projecting about an inch

beyond it. There are two sets of screw stops, one touching the end of the bar, the other the end of the spring. They are so adjusted that the spring shall make contact with the outer screw before the motion of the bar is stopped by the inner one, thus giving a double contact, which is very advantageous when currents are weak.

383. The longer the circuit on which a relay is placed, the longer and finer must be the wire of the coil; but it is convenient in practice to adopt a coil of medium resistance because of the difficulty in obtaining proper care in selecting the best suited for each circuit. Want of care and defective information are the greatest obstacles to improvement in telegraphy.

384. The polarized relay can be adjusted either to fall back after having made contact, or to remain indifferently in either position. It will, in the latter case, remain where it has been placed by a current, until the arrival of a current in the reverse direction causes it to assume the opposite position, and will produce dashes and dots at pleasure from key contacts of equal duration; the length of the *mark* will depend upon the interval between the direct and the reverse currents. With this apparatus Morse signals can be produced by induced electricity. An important use is made of this principle in the automatic telegraph.

385. The ink-writer is sometimes made with a polarized electro-magnet on the same principle as Siemen's relay, and can then be worked by line current.

386. *Prevention of spark in relays.*—Every time a local battery circuit is opened or closed by a relay, a spark passes which burns away the metal at the points of contact. The spark, at breaking contact, is much the stronger of the two, because of the *extra current* (174) developed in the wire of the electro-magnet. It may be prevented in two ways. The ends of the magnet coil may be connected by a resistance coil, in the manner of a shunt, through which the extra current will pass, instead of darting through the air.

The shorter the wire of this shunt is, compared with its resistance, the greater its effect. It should be made of very fine iron wire, wound half right-handed and half left-handed, so that no induction may take place in the shunt itself, and its resistance should be about 40 times that of the electro-magnet.

This arrangement is adopted in Dujardin's type-printer, where a powerful local battery is employed.

Or a *condenser* (143) of tinfoil may be placed between the terminals of the electro-magnet. The surface of tinfoil required will vary with the length of the coil and the strength of the battery, but five or six square feet will probably suffice.

Notes as to the Management of the Morse.

387. (*a*) Whatever tends to make the running of the paper irregular is apt to shorten dashes into dots, or to cause dots to be lost altogether. This happens when the style is adjusted so as to mark the paper too deeply, when the paper sticks in the guides from irregularity in width, and when it does not run freely from the drum on which it is held.

(*b*) If the style is not so adjusted as to move freely in the groove in the upper friction wheel, the signals will fail more or less; and if it is so much on one side as to be completely out of the groove, no marks at all will be produced. These faults generally arise from too much end play in the pivots of the lever, or from the screws working loose. When the lever works too loosely in its bearings, irregular dashes, too deep at their commencement, but tapering off to nothing, are produced; when the armature is first attracted the style indents the paper, but the forward motion of the band causes the lever to recede in its bearings until the style ceases to mark.

(*c*) Residuary magnetism (130) frequently causes the armature of the electro-magnet to *stick*, or remain attracted, and can be prevented by occasionally reversing the connections so as to

make the current pass in the opposite direction. The armature will always *stick* if it is allowed to touch the core, because the polarity of the iron will not cease when the current is cut off. The screw stop should therefore be adjusted so as to prevent the armature approaching the poles of the electro-magnet too closely, and if the current is so feeble that the armature must be allowed to approach as closely as possible, a piece of writing-paper may be laid over the poles of the electro-magnet, to prevent actual contact.

(*d*) When the current flows in the wrong direction through the relay, so as to complete the local circuit by the *reversed* instead of the *printing* current, signals are reversed, or the spaces between signals printed, instead of the signals themselves, and the marks on the paper will frequently be dots only. To remedy this fault, the wires of the relay, or the batteries of the sending station, must be reversed.

(*e*) If, when the line current moves the *relay*, the Morse *machine* does not print, the fault will be in the local circuit; arising from dirt on the relay, contact from a broken wire, a loose connection, a faulty cell, or loss of power in the local battery. If the machine does not print when the relay is moved with the finger, the local circuit is certainly defective.

It must be borne in mind that, as the local battery is placed on a circuit of feeble resistance, it will consume much more sulphate of copper than the line battery, and therefore will need greater attention.

(*f*) For the same reason the pivots and contact points of a relay are apt to be oxidized, or even burnt, and the bar should always be connected to its bearings by a fine spring, or by a drop of best salad oil, which will convey the current and protect the pivot points. When the local batteries are so joined up that the copper is connected to the bar, the oxidation takes place at the pivot, sometimes completely insulating it and breaking continuity. The copper current should

therefore always be made to flow from the bearings to the pivot, not *vice versâ*.

A local battery consisting of large cells frequently causes a relay to stick by fusing together its points of contact, which must be kept clean and bright by scraping with a knife or very smooth file. Small cells do not fuze metals so rapidly, but, on the other hand, they are more apt to cause oxidation.

388. MODIFICATION OF THE MORSE ALPHABET.—From the date of the introduction of the Morse system, it became apparent that much time and paper ribbon would be saved if the alphabet could be constructed of dots only, arranged in two parallel lines, because the dash occupies thrice the time of the dot, and three times the length of ribbon. This was easily effected by a double key and two electro-magnets, with polarized armatures or relays, one actuated by the positive, the other by the negative current.

As the single-needle alphabet is formed from the Morse, by representing dashes by a movement to the right, dots by a movement to the left, this double recording instrument could be inserted in a single-needle circuit—or, in other words, the single-needle signals could be recorded by it. It could obviously also be placed in circuit with a bell. These advantages are palpable, and consequently many attempts have been made to introduce it.

As it was found there might be a difficulty in determining quickly in which of the two lines a series of dots might be placed, attempts were made to represent the dash by a line vertical to the paper, thus |, so that the letter V, which in the Morse alphabet is . . . —, would be written . . . | . This removed all difficulty in reading, but the line was not easily produced by the ink-writer, and a double dot was substituted, the V being written . . . :, which is read with equal facility.

But the same electrical difficulties and multiplication of adjustments obtain here as in the case of the bell.

389. TRANSMISSION BY TWO STATIONS AT THE SAME TIME UPON A SINGLE WIRE.—This system has not been found of practical advantage, but it is described as being one of the most remarkable in telegraphy.

The principle of this method of signalling is this :—

Let D and D′ be differential galvanometers at the opposite ends of the circuit; one coil of each of which is connected to the key K or K′ and the line wire, the other coil to the key and through the rheostat R or R′ to the earth E or E′.

The rheostats are adjusted from time to time, so that their resistance shall always be exactly equal to that of the line wire.

When a current is sent by the key K, it splits or divides into two equal portions, because the resistances of the two paths

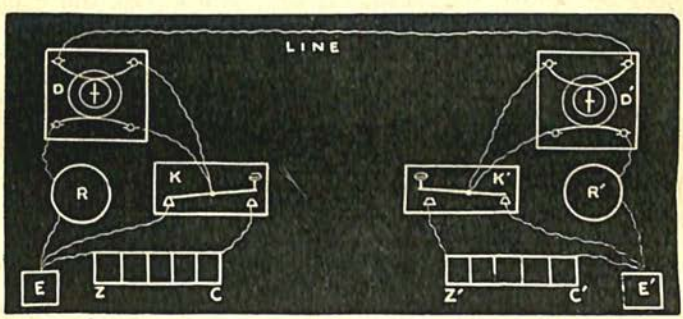


FIG. 95.

are equal. Each portion passes through the galvanometer, but in opposite directions, and having consequently an equal but opposite effect on the needle, the needle remains at rest. One portion then traverses the rheostat R to the earth, the other follows the line wire to D′, passes round the coil to K′, and there again divides between the direct route to the earth through the key, and that through the other coil of the galvanometer and the rheostat R′, the latter current being extremely feeble, because of the extra resistance. The needle D′ moves and records a signal in the direction of the stronger current.

If the key K′ is pressed while this is taking place, the current sent will, as in the former case, split equally between the coils of the differential D′, and for the same reason have no effect on the needle D′; which, being thus uninfluenced by the outgoing current, will move in obedience to the signal sent by the other station. At the same time, that portion of the current which passes to the line wire from K′ will either assist or oppose the current proceeding from K, and will, in either case, disturb the equilibrium in the differential D, recording a signal at that station.

When the resistance of the line wire varies, from rain or other causes, the rheostat must be altered so as to restore the equilibrium of the *outgoing* current in the coils of the galvanometer, so that the current sent by the key shall never move its own needle.

SWITCHES OR COMMUTATORS.

390. These are employed for connecting one circuit to another, for dividing a circuit, or for any purpose where connections have to be altered.

In the *lever switch*, a lever or spring is removed from one stop to another by a pin projecting from a moveable axis, or the pin places the axis itself in connection with the lever or spring.

Thus, suppose it to be required to divide the line A B C at the central station B, so as to enable each half to be worked independently:—

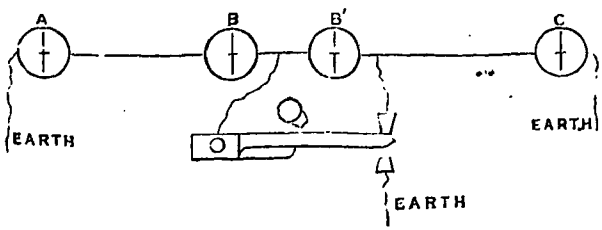


FIG. 96.

(1.) In this position of the switch a signal will pass through the entire line, with the exception of the second instrument at B (viz. B′), which, not being necessary, is connected across or or placed on *short circuit*. No current will pass through B′, because the resistance of its coils is infinitely greater than that of the lever which connects the two ends of the coil wire.

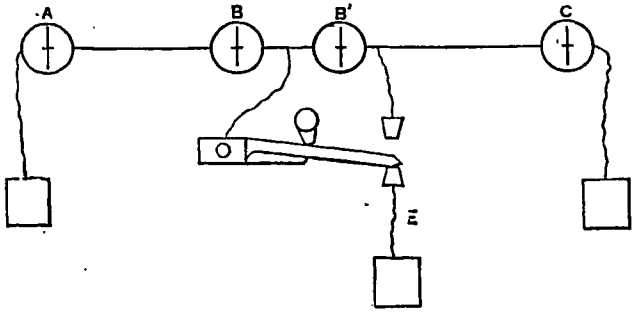


FIG. 97.

(2.) In Fig. 97, the switch divides the line into two independent portions, by *putting on the earth* between the two instruments B and B′. As B′ is now required it is thrown into circuit.

With a peg switch the arrangement would be:—

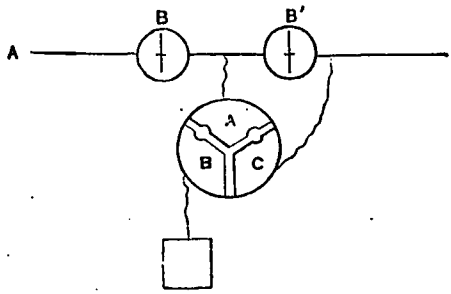


FIG. 98.

(1.) The peg placed between A and C, to work through the whole line.

(2.) The peg placed between A and B, to divide the line into two circuits.

If it be required to connect the line A B either with the line B′ C or B″ D, or to make the three lines A B, B′ C, B″ D independent circuits :—

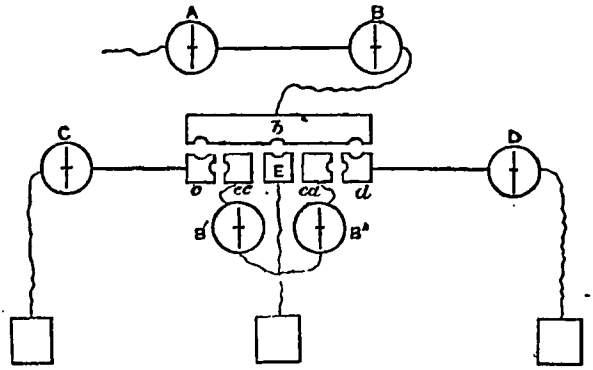


FIG. 99.

(1.) A through B to C, D and B″ forming a separate circuit.
Place pegs to connect *b* and *c*, *d* and *ed*.

(2.) A through B to D, B′ and C forming a separate circuit.
Pegs connecting *b* and *d*, *c* and *ec*.

(3.) Each circuit separate, *i.e.* A to B, C to B′, D to B″.
Pegs connecting *b* and E, *c* and *ec*, *d* and *ed*.

The same changes may be effected with a switch of three levers.

391. The *Commutator* or *Universal Switch* (Fig. 100) enables us to connect any two circuits.

Two sets of rods or plates of brass, insulated from one another, are fixed at right angles ; holes are drilled through both sets, so that when the peg is placed in any one of the upper holes, it can be passed through the corresponding hole in that bar of the lower set which is directly under it. Thus any of the upper bars can be connected to any one of the lower.

The peg fits tightly in the upper set of holes, and spring-tight in the lower set. This switch must be carefully kept clean.

The peg switch allows of the greatest number of combinations, and is the cheapest; but the lever switch is more readily

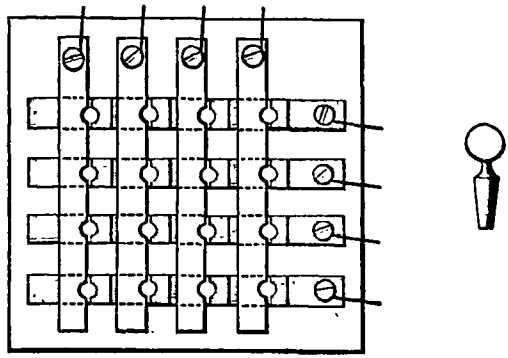


FIG. 100.

manipulated, and is not so liable to be *left wrong* carelessly, so as to disconnect the line. The latter form is especially serviceable when it is required to change several connections at the same time.

392. It is sometimes required to cut an instrument or bell out of circuit.

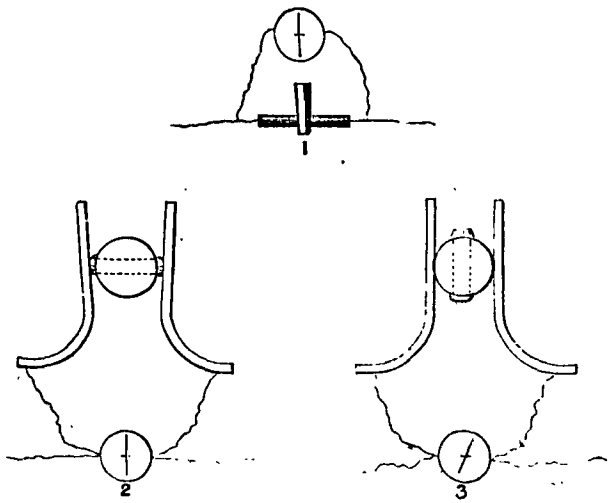


FIG. 101.

No. 1 (Fig. 101) is a peg switch, placed between two brass plates connected with the two ends of the coil wire. Nos. 2 and 3 are different positions of a lever or spring switch, through the moveable axis or *barrel* of which is passed an insulated peg. When the peg is placed in the hole as in No. 1, or when the barrel is turned in the position shown in No. 2, so as to connect the two springs metallically, no current will pass through the galvanometer. If the peg is removed, or the barrel turned into position 3, the short circuit is broken, and the current passes through the coil. A switch of this kind attached to an alarum is called a "*silent.*"

TRANSLATORS.

393. When a circuit exceeds a certain length, the line current becomes so much enfeebled, that even if a very large battery is employed at a sending station, signals will not pass. In such cases messages were formerly *transmitted*, that is, read off at one or more intermediate stations and sent on afresh. This duty is now performed automatically by a *translator* or *repeater*. The principle of translation (carrying beyond or forward) is to cause a relay to complete the circuit between a battery and a second *line wire*, in the same manner as that in which the local circuit is completed between the battery and *the Morse*.

394. Fig. 102 shows the principle, in its simplest form, by which signals may be translated from a distant station B to another at A, on the *single current* system.

Let the two screws which limit the movement of the Morse lever be insulated from each other, and from the lever itself. Let the line wire B, *from* which the signals are received, be connected through the electro-magnet coils to earth; let the line wire A, *to* which the signals are to be translated, be connected to

the lever; the earth to that screw on which the lever lies when at rest; one pole of the translating battery to the screw to which the lever is attracted when a signal is being received, and the other pole to the earth.

When no signals are passing from B, the lever puts the wire A to earth. When a signal is received from B, the lever is moved from the screw connected to earth, and is made to touch the stop or screw connected to the battery, so that the line wire A is dis-

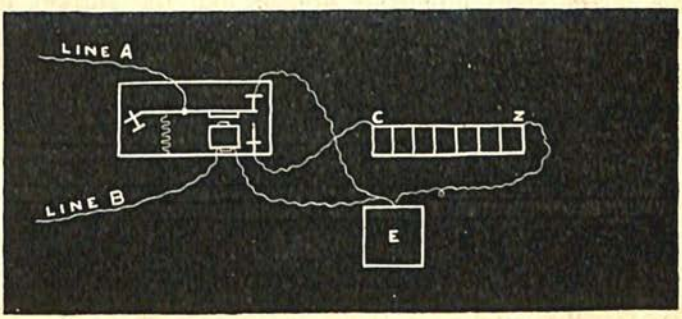


FIG. 102.

connected from the earth and placed in contact with the battery. The signal received on the Morse through the wire B is thus *sent forward* (translated) *to* A. By a chain of such arrangements signals may be sent automatically to any distance, or signals may be made to *radiate* from the intermediate office to the several circuits in connection with it, by means of their respective Morse levers.

395. But in order to enable A and B to speak to each other, or to effect translation in *both* directions, a second translator is required at the intermediate station, and if it be desired to work the two circuits separately, a *switch* is necessary to alter the connections. (See Fig. 103.)

396. The lever of the translator moves through a certain space before making contact with the battery, so that the duration of the current sent forward is shorter than that received from the distant station. A second translator shortens it still

SINGLE CURRENT TRANSLATOR.

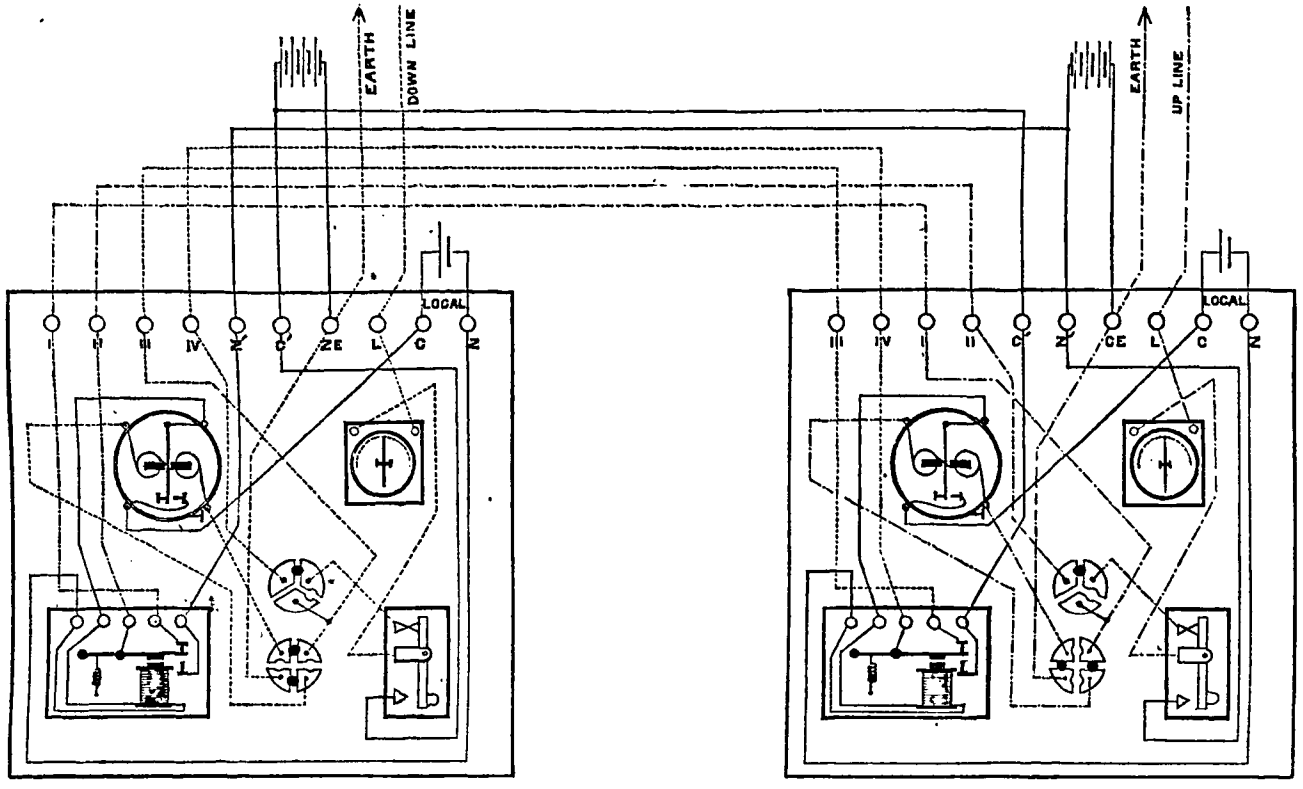
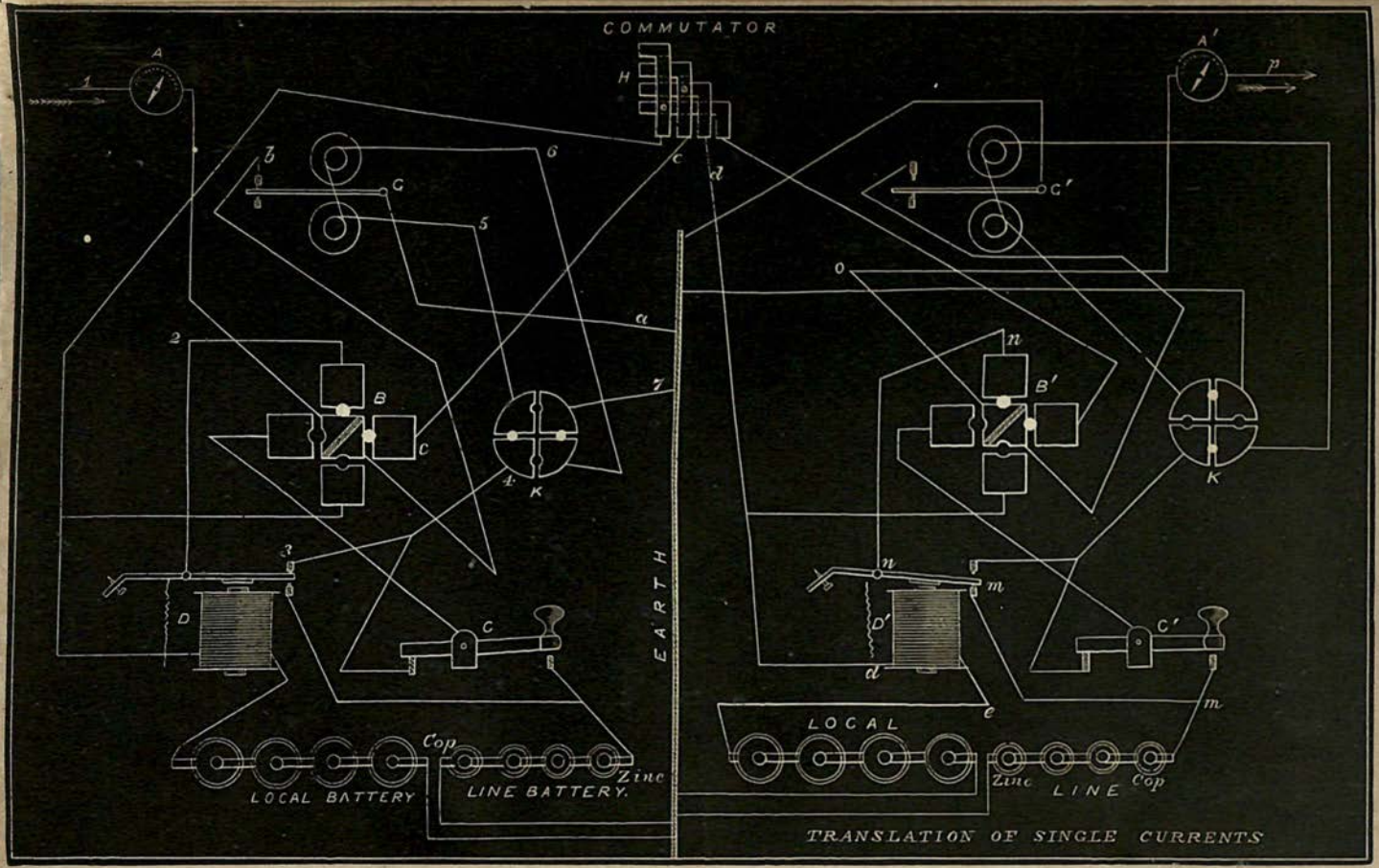


FIG. 103.


COMMUTATOR
A
A'
H
1
p
b
G
G'
c
d
5
0
a
2
z
B
B'
C
K
4
n
m
D
D'
C'
e
EARTH
LOCAL
Cop
Zinc
LOCAL BATTERY
LINE BATTERY.
Zinc
LINE
Cop
TRANSLATION OF SINGLE CURRENTS

more, so that the dots cease to be translated, or are lost. The sending clerk must therefore key more firmly than usual, increasing the length of his contacts, especially when sending dots; and springs must be fixed to the lever of the translator, as shown in Fig. 104, to improve the contacts by giving a slight rub, and to lessen the time lost by the movement of the lever.

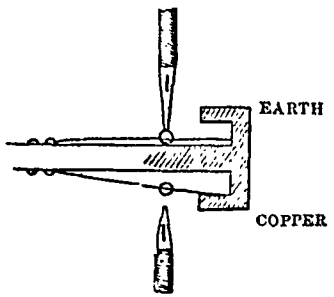


FIG. 104.

In all keys, relays, and other apparatus for sending currents, there is a very great advantage in a rubbing contact over a mere blow. When there is a great loss from leakage on the line, it is most advantageous to prolong the contact of the key by a spring, so that a larger quantity of electricity may flow to the line.

397. SINGLE CURRENT TRANSLATOR.—The diagram shows the system adopted at Amsterdam for home traffic.

A A′ are the galvanometers, B B′ the small commutators for dividing or connecting the lines, C C′ the keys, D D′ the Morses, G G′ the relays, and K K′ the relay switches for changing when required the direction in which the line current passes through their coils, H the great commutator for connecting the several lines.

The diagram shows a current in translation from A to A′; the numerals indicating the course of the *received* current, the small letters from *a* to *e* that of the current in the *local* circuit closed by the relay G; and the small letters *m* to *p* that of the *new* current translated forward by the action of the Morse D′.

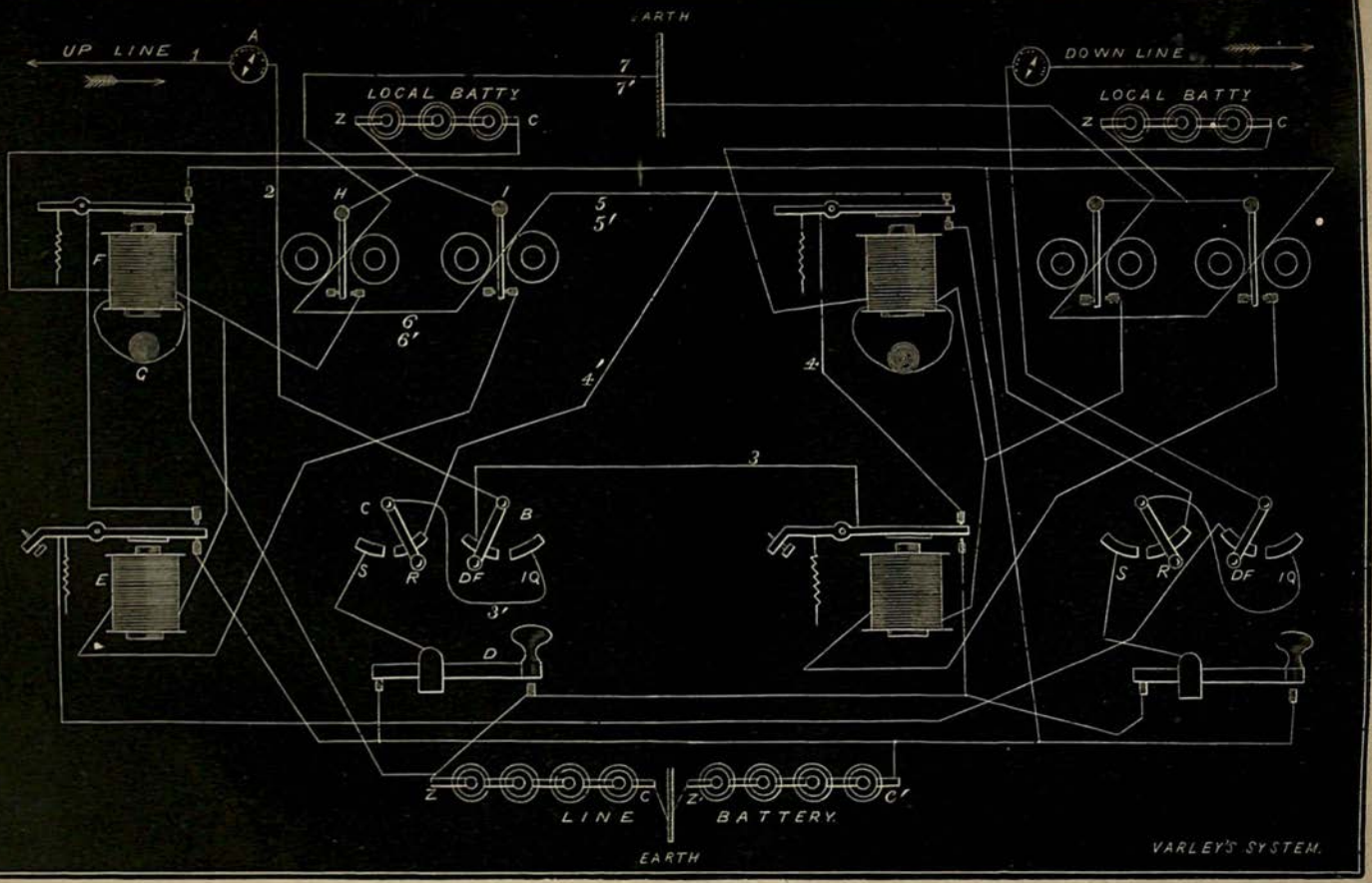
To arrange the apparatus for working the circuits independently, the pegs in B and B′ are shifted into the unoccupied holes, which places the keys C C′ in circuit, disconnects the levers of the Morses D D′ and the commutator H, at the same time placing the Morse coils in circuit with their own relays.

No special apparatus, except the switches or commutators, is needed. The *great commutator* is a variety of the system of cross-bars described at p. 226, to which every important instrument is connected, so that any two may be connected in translation.

At Amsterdam, and in Holland generally, a single large line battery and a single local are used for all the instruments at a station.

398. DOUBLE CURRENT TRANSLATORS, WITH RELAYS.—*Varley's System.*—This apparatus consists of two complete sets of printing instruments, each consisting of a Morse, two relays, an automatic switch, two ordinary switches, a galvanometer, and a key. It is so arranged that the two circuits can either be worked independently, or be connected for translation. In the diagram, the apparatus on the left of the earth wire is connected to the up line, that on the right to the down line, and is shown as arranged for *translation.* A is a galvanometer placed in the line wire, B the *line* switch dividing the circuits or connecting them for translation, I the receiving relay which closes the local circuit containing the Morse E, F the automatic switch for reversing the current, G a shunt for prolonging the duration of the current in the coils of F, and H a relay wound in the reverse direction to the relay I.

In this system the line wire is traversed by a current at all times during the passage of a message; which is reversed after each signal, so that it is alternately positive and negative. When the two circuits are divided and the translator not in action, the lever B of the line switch is turned to I Q, so as to connect the line wire with the lever C of the key switch. In sending, this lever C is turned to S (send), and the key is then connected to line, so that each time the key rests on its back stop a reverse current flows to line from a battery connected to this stop, and joined up in a reverse direction to the sending battery.


EARTH
UP LINE
A
LOCAL BATTY
Z
C
7
7'
DOWN LINE
LOCAL BATTY
Z
C
2
H
I
5
5'
F
C
6
6'
4
4'
3
C
B
S
R
DF
IQ
3'
E
D
S
R
DF
IQ
Z
C
LINE
Z'
C'
BATTERY.
EARTH
VARLEY'S SYSTEM.

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In order to enable the distant station to reply, the line must be disconnected from the key, and connected to the receiving relay. This change is made by turning the switch C from S to R (*send* to *receive*), and it is evident that in translation this change cannot be made by hand, but must be effected automatically.

Now, in translation, the lever of the Morse takes the place of the key, the key itself having been disconnected by the switch B. The *upper* stop of the Morse lever performs the duty of the *back* stop of the key, and the *lower* stop of the lever the duty of the *battery* stop of the key. The former is connected with the reversing battery in sending, and with the relay in receiving, by the automatic switch F. It is necessary that this switch be *held in contact* with the lower stop during the whole period signals are being *sent*, in order that a reverse current may flow to line during the *interval* between each signal; and that it shall rise during any *pause* in signalling, so as to connect the line with the receiving apparatus, and enable the distant station to reply. It must, therefore, be held down, not only by the marking current, but also by the reversing current from the distant station, and for an *instant* after, so that the reversing current sent forward by the lever of the Morse in rising, shall have sufficient duration to act upon the instrument to which the signal is sent forward.

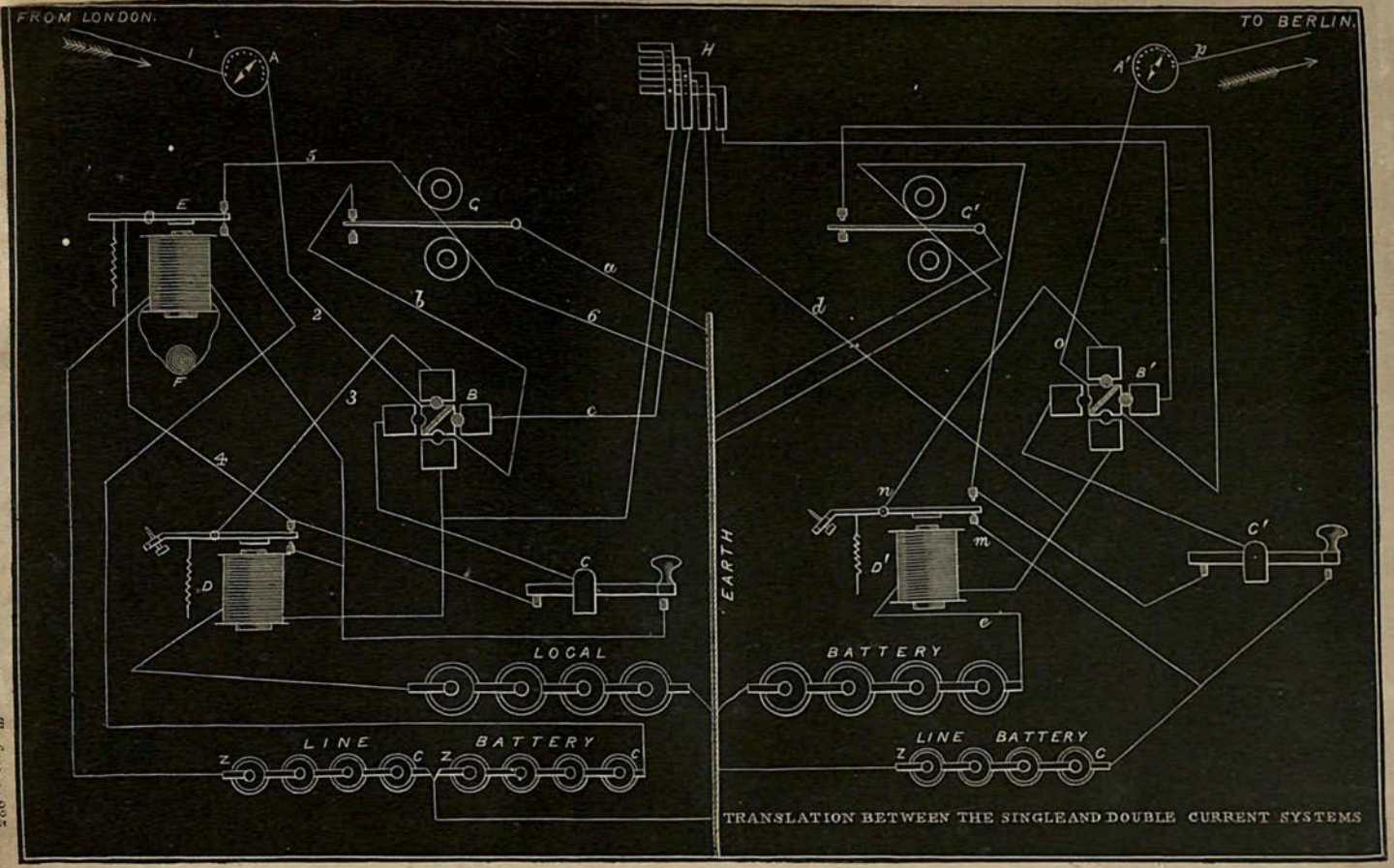
To effect this, the electro-magnet of the automatic switch F is placed in the local circuit containing the Morse E, so that both it and the Morse are acted on by the relay I, and held down by it during the *signal*. It is also placed in a second local circuit closed by the relay H, by which it is held down during the *reversed* current. These relays, H and I, are wound in opposite directions, so that the sending current moves I, but its effect on H is to press the bar more firmly against the insulated stop, to which no wire is connected. The reversed current, on the other hand, moves H, but presses I against its insulated stop. I moves

both F and E, *while* H *moves* F *only*. The lever of the automatic switch F is therefore held down to "send" by both the direct and reverse currents, but, were there no other force acting on it, it would rise instantly they ceased, so that the switch would be turned to "receive" before the Morse lever could touch its upper stop. No reversed current would in this case be sent forward to the distant station. It is, however, held down an instant *after* each current ceases, by a special arrangement which allows it to move rapidly *from* its normal position, but regain it so slowly that it shall not *have time* to do so until a pause occurs in the signalling.

This effect may be attained by placing a secondary battery (56) in the local circuit of F, so that the polarization caused by the local current which flows through it when the circuit is closed by H shall hold down the lever of F for a second or two; but in practice it is found that as the duration of the current of polarization depends upon that of the local current, it is apt, when the local circuit has been closed for a longer time than usual, to hold the lever down too long.

The required retention can be obtained without this defect by shunting the electro-magnet F by a resistance G about equal to its own, so as to afford a path for the extra current direct (175), which, passing through the magnet coils in the same direction as the battery current, retards its demagnetization. The duration of this retardation may be adjusted, within certain limits, by varying the resistance of the shunt, and the method appears to be free from objection. The power of the electro-magnet is somewhat reduced, but not inconveniently so.

The diagram is arranged to show a current in translation from the up line to the down, the figures denoting the successive steps of its path. The marked figures show the steps of a *received* current when the line switch is I Q and the circuits divided, the alteration of path commencing at B. The apparatus is shown



TRANSLATION BETWEEN THE SINGLE AND DOUBLE CURRENT SYSTEMS

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arranged for translating permanently between *the same* two lines, but if it be required to translate between *any* two of the lines running into the station, a distinct set is required, which may be connected up to any two lines at the testing box, or by an universal switch.

399. TRANSLATION BETWEEN THE SINGLE AND DOUBLE CURRENT SYSTEMS.—*Varley's method.*—The diagram shows Varley's arrangement for translating between a single current and a double current system, as at Amsterdam, where the English system meets the single current system of the Continent.

The shunt F is shown, instead of the secondary battery, for holding down the lever of the automatic switch E.

The diagram shows a current in translation from London to Berlin.

H is the *great commutator* by which any Continental wire may be connected to any London wire, A and A′ are the galvanometers, B and B′ the *small commutators* for altering the connections from translations to independent working. C and C′ are the keys, D and D′ the Morses, E the zinc sender to reverse the current in the cable between the signals, F the shunt for preventing the lever rising too quickly, G and G′ the relays for working the Morses. The numerals show the course of the current received from London, the letters from *a* to *e* the local circuit closed by the relay working the Morse D′, and those from *m* to *p* the current sent forward to Berlin. The two sets of apparatus can be worked separately by removing the pegs in B and B′ into the unoccupied holes.

400. As has been said already, particular care must be taken to keep the lever of the automatic switch firmly down while signals are passing, otherwise the marks will be confused, or may appear at the receiving station as a continuous line, owing to the failure of the spacing current; and when a cable is included in the circuit, should the lever rise during the transmission of signals, it will allow the discharge (or return current) from the

cable to find its way to the opposite side of the translator, so as to destroy the signals from the sending station.

401. The diagram shows a translator for very rapid working, in which the loss of time arising from the space through which the Morse lever has to move is avoided. The current is sent forward not by the Morse, but by a third relay F F′, the Morse itself being used only as a recorder. The relay bar may be adjusted so as to move through but a very small space, while the Morse must have sufficient play to mark the paper.

A and A′ are the galvanometers, B and B′ the double current keys, C and C′ the Morses, D and D′ the spacers or automatic switches, E and E′ the shunts for preventing the levers of the spacers rising too rapidly, F and F′ the transmitting relays placed together with the Morse in the local circuit, G and G′ are the relays actuated by the marking current, H and H′ those acted on by the reverse or spacing current; these two sets of relays are connected reversely, so that the one obeys a positive, the other a negative current.

In the diagram the relays are shown at rest, but supposing a marking current being sent from the "up" station, the marking relay G is drawn over, putting a current from the local battery through the transmitting relay F, the Morse C, and the spacer D, which are held down, F sending a marking current through the galvanometer A′ to the down line. When the sending station raises his key, he reverses the direction of his current, releasing the relay G and closing the local circuit through the spacer D only, by means of the relay H: the Morse and the marker return to their resting position, but the spacer is still held down, and a reversed or spacing current takes the place of the marking current through the galvanometer to the "down" line.

The up line circuit is shown by dotted lines, the down line by alternate dots and dashes, the battery circuit by continuous lines.

The large switch arranges the connections either for translation or for working the two circuits independently. The letters

and numerals have the same signification as in the foregoing diagrams.

In this translator the adjustment of F and F′ is very important. The relay bar depends solely upon the attraction of the poles of the polarized electro-magnet for regaining its position of rest against the back stop, as no reverse current passes through it. It must, therefore, be adjusted so as to have a decided tendency to fall back rapidly after each signal, for otherwise the spacing current will not pass out to line.

When this relay is used for translating the signals of the automatic system its action can be tested only by the ear, for its movements are too rapid for the eye to follow, especially with such small play as is necessary to avoid loss of time in relaying the currents. The reversals will also fail unless the local relays are so adjusted as to keep the spacers D D′ firmly down during the whole time that signals are passing, and care must be taken that the spacer rises when the sending station moves his key-switch to *send*, or a current remains on the line, and the receiving station will be unable to reply.

It is very necessary that all points of contact be kept bright and clean. They require more frequent attention in damp weather than in dry, because the moist atmosphere assists the formation of the oxide, which offers great resistance to the passage of the current, and sometimes causes a spark to bridge across the short space between the battery stop and the lever, thus putting a permanent current on both lines, and entirely stopping the working.

The play between the contact points should not be so small as to risk the occurrence of this fault.

The adjustment of the spacing relays H H′ should allow the bar a little more play than in the other relays, because unless the contact is properly broken after each reversal the marks will fail on account of the battery current finding a short route through the spacer only, instead of through the Morse

marker and spacer, as it is intended to do when the marking relay acts.

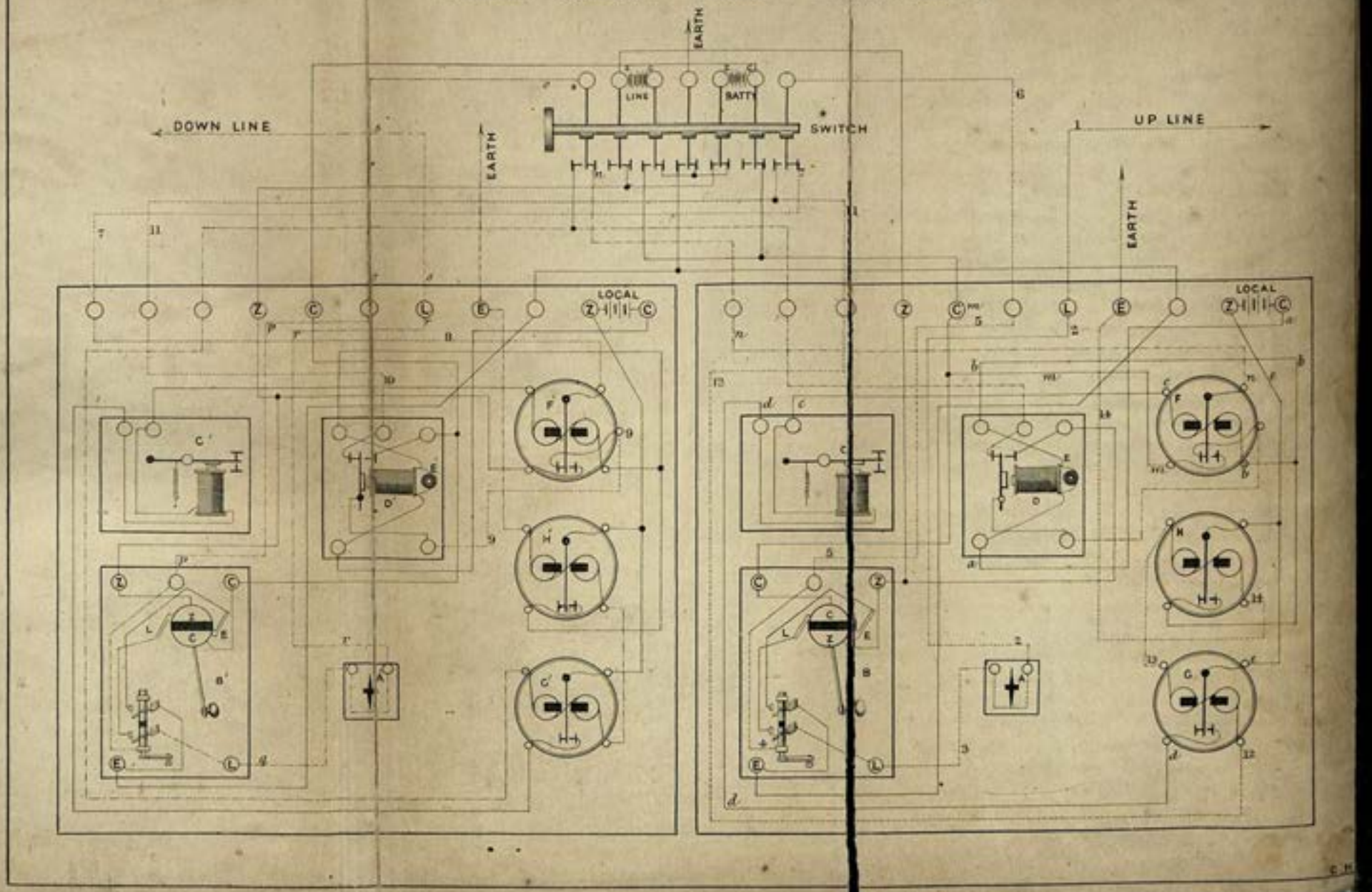
The bar of all relays should have sufficient play to break contact with one of the stops before it makes contact with the other. When the relay connected with the automatic switch is not properly adjusted in this respect, the local current, instead of acting upon both the Morse and the switch, will move the switch only.

402. Special attention must be given to the batteries attached to relay apparatus, as they are worked very hard. The most *constant* form should be selected, and exchanged as soon as the plates become thin. About 30 cells for each local, and 70 to 80 for sending sets, in ordinary cases should be sufficient. Weak or defective battery power gives rise to more complaints against the relay than any other fault, and, therefore, must be carefully guarded against by frequent tests, and personal examination of the cells when any doubt exists. Worn plates are often very deceptive, and in testing them the current should be passed through the galvanometer for several minutes, and if any falling off of the deflection can be observed, the set should be at once changed.

403. It is necessary that translators should be superintended by an efficient clerk who is able to read by sound, so as to hear what is passing and detect immediately when adjustment is necessary. If an embossing instrument is used, the paper band should be removed, in order to allow the lever to move freely.

In cases of apparent inattention to a call, the clerk in charge of a translator should satisfy himself that no fault exists in the apparatus under his care, which would prevent the reply passing his station. This can be ascertained in a measure as soon as the calling station pauses, by closing the line switch on the side from which the reply should be received, thus enabling the reply to find its way direct to the relays without first tra-

DOUBLE CURRENT MORSE TRANSLATOR



versing the levers of the opposite translators, as an oxydized point of contact, or loose connection, would interfere with its passage. The most certain method, however, is to send a current from the testing battery through that portion of the apparatus in which the fault is suspected.

404. *The Hughes Type-printing Instrument.*—This apparatus differs from all others in that it is mainly mechanical, the electrical action being confined to the sending a single short current at the instant the type-wheel is in the proper position, and only one wave is needed to produce a letter.

The sending and receiving instruments are precisely alike, and are manipulated by a keyboard of as many keys as there are letters and signs to be printed.

Connected with the keys is a set of *pins* arranged radially in a circular horizontal plane, through the centre of which a vertical shaft passes, driven by clockwork and carrying a horizontal arm called the *chariot,* which sweeps round a little above the pins and without touching them. When a key is pressed, the corresponding pin rises sufficiently high that, when the chariot next passes, it touches it, and sends a current through the instrument coils to line.

The type-wheel is fitted spring tight upon an axis geared into the shaft which carries the chariot, so that while the two move together the type-wheel can yet be shifted in position, or even stopped, without stopping the wheelwork. If the chariot and type-wheel are adjusted so that the former shall touch the pin which has been raised by depressing the key, and thus send a current to line at the instant the corresponding letter is opposite the paper; it follows that if the paper is at this moment lifted into contact with the type, by means of the current, the required letter will be printed.

The speed is regulated by a vibrating spring carrying a weight, and any small error in the position of the type-wheels caused by one instrument running faster or slower than the other, is

rectified by the *correcting lever*, which forces a wedge between the teeth of a star-wheel fixed upon the type-wheel, and brings it into position.

The current is made to print the letter in this way :—A hollow shaft carrying three cams is fitted upon the axis of a wheel which gears into that which drives the type-wheel. This hollow shaft is not carried round by the axis which passes through it until the two are locked together by a detent, which is itself put into action by the current passing through the coils of an electro-magnet.

The two then revolve together, and the following actions take place :—

(1.) The first cam corrects the type-wheel as to position.

(2.) The second cam presses the paper against the type.

(3.) The third cam moves the paper forward.

(4.) The connection between the cam shaft and the axis which passes through it is broken, and the cam shaft comes to rest. A fourth cam replaces the armature upon the electro-magnet, and the apparatus is ready to receive a second current.

The electrical arrangements, though simple, present several specialities.

The electro-magnet consists of two soft iron cores wound with covered wire, and each fitted upon a pole of a permanent magnet. The armature is soft iron, and when placed upon the electro-magnet is retained in position by the polarity induced in the cores by the permanent magnet. A spring, adjusted by a screw, tends to remove the armature.

If a current passes through the coils in such a direction as to develop polarity contrary to that induced by the permanent magnet, the armature is released, and immediately it has quitted the cores it moves sharply and forcibly under the full force of the spring, and liberates the detent. The armature is replaced by the action of the wheelwork.

The amount of attraction between the cores and armature is

regulated by a soft iron keeper which can be placed across the permanent magnet.

This arrangement is exceedingly sensitive. Suppose that the induced magnetism in the cores holds the armature with a force represented by 100, and that the spring opposes a force of 91, a contrary polarity of only 10, produced by the current, will liberate the armature, and when it has once left the cores, it will rise with the whole force of 91; and as it is replaced by the wheelwork, the spring which acts upon it may be set stiffly, for the current has not to overcome it. The instant the armature rises the coils are short circuited, and the received current passes direct to earth. Suppose 100 parts of current arrive, and that five only are required to release the armature, the surplus will pass direct to earth.

When the armature is replaced upon the electro-magnet by the action of the wheelwork, an *extra-current*, in the same direction as the received current, is produced. This acts a if it were a new current caused by the touching of a key, and if the resistance of the line be small, it produces a continued to and fro action of the armature, and a succession of letters are printed.

Its formation is prevented by the breaking the circuit of the electro-magnet by the cam shaft immediately it commences to turn, so that at the time the armature is replaced there exists no circuit for the extra-current.

The apparatus can be employed as a chronoscope to compare very short intervals of time.

For this purpose the correcting cam is removed, so that the type-wheel is not adjusted at each impression.

If the instrument is on short circuit, and a key is pressed, the corresponding letter will be printed.

But if a long wire is placed in circuit, a certain time will be occupied in the passage of the current, and the release of the armature will be delayed, so that if key *A* be pressed, the letter

A will not be printed clearly, or it may be *B* or even *C* may be printed, according to the distance the type-wheel has run during the time the current has been retarded.

Now suppose the type-wheel makes 120 revolutions per minute, or two each second, and there are 28 letters or figures engraved around it. Each sign will pass the printing lever in $\frac{1}{56}$th of a second, and if the retardation be that interval of time, the instrument will print a letter in advance. Again, if the speed of the type-wheel be adjusted to 107·25 revolutions, each letter or sign will pass the printing lever in $\frac{1}{50}$th of a second. If then the retardation be $\frac{1}{50}$th of a second, *B* will be printed for *A*, if $\frac{1}{100}$th, *C*, and so on.

AUTOMATIC SYSTEMS.

405. Although a good manipulator may be able to send 40 or more words a minute by the Morse key, practically a very much lower rate is attained; the exertion cannot be sustained; and however expert a clerk may be, his signals are not always clear and legible. If, therefore, a machine can be employed which shall do nothing more than transmit signals at the maximum speed which can be attained by hand, the usual advantage of machine over hand labour will have been gained. The machine will not tire, and its signals will be always perfectly formed and clear.

When the speed of signalling is considerably increased upon a land line, causes of embarrassment arise similar in many respects to those which occur in buried wires. It is found that speed is increased by reversing the current after each signal. But the limit of speed for the Morse alphabet is soon reached when the length of the dots and dashes is determined by the *duration* of the battery currents.

A succession of dots can be signalled much more rapidly than dots and dashes, because the battery contacts are of uniform

duration, and the charge in the wire uniform also, whereas a dash charges the wire more highly, and therefore requires a larger reversal, or a longer time for its discharge. In addition to this effect of inequality in the duration of the currents, there appears to be also an important action upon the receiving electro-magnet; for if a current is prolonged the iron is more strongly magnetized, and therefore requires more time to become neutral. Thus at high speeds the signals are distorted because the effect produced by the first current has not entirely ceased before a second begins to act; so that a dot following a dash tends to run into a line, and the first dot after a space fails.

406. For these reasons, the system introduced by Bain, in which the ordinary Morse characters are punched out in a paper ribbon and are transmitted by means of a brush of wire resting upon the ribbon and making contact with a metallic roller through the holes cut in the paper, has a comparatively limited speed, because the currents are variable in duration and always in the same direction.

This system was employed in 1852 between Liverpool and Manchester, but was abandoned partly because the insulation of the wires was not then sufficiently good, but principally because no convenient method of perforating the paper had been contrived. It, however, succeeds very well at a moderate rate of speed upon a well-insulated line of 60 or 70 miles, and would probably be successful over a longer distance.

The punching apparatus can be made in a simpler form if the perforations are arranged in parallel lines, one for dashes, the other for dots. The same wire brush will make contact through both rows of holes, and the received signals will be unaffected by the alteration.

407. The Morse alphabet can be produced with currents of equal duration by using a polarized armature, so adjusted as to remain, after the contact is broken, in the position into which it is moved by the sending current until a reversal is sent, or, in other

words, to have no tendency to move at all except as influenced by the current. Under this system a dot is produced by a short positive current, followed instantly by a short negative current, a dash by a short positive current followed by a pause of sufficient duration to allow the style or inking disc to form a dash, then a short negative to remove the style from the paper. Sixty words a minute cannot be safely attained, even on land lines, without this arrangement.

408. Siemens as well as Wheatstone has adopted this principle. Siemens arranges the wire brush and perforated band so as to produce signals by reversed currents of equal duration. The armature of the receiver being polarized, and so adjusted as to remain in the position in which it is left by the last current, it follows that after a marking current has been sent, the inking disc continues to produce a line on the paper until it is removed by the reversal. Thus a dot is produced by an instantaneous current, immediately succeeded by a reversal; a dash by an equally short current, reversed after an interval sufficient to allow a dash to be formed on the paper. The edge of the wheel, on which the paper rests, instead of being in one piece, as in Bain's apparatus, is divided into a number of teeth, connected alternately to the positive and negative poles of a battery, so that if the brush rests upon the wheel when the paper ribbon has been removed, a series of reversals is sent along the line. The holes in the paper ribbon are so arranged that, if a dot is required, the wire brush makes contact with a positive tooth or division of the wheel, and immediately after with the next tooth, which is negative; a marking current is therefore sent and reversed instantly. If a dash is required, the holes are so arranged that the second or reversed current is produced, not, as before, by the *next* tooth to that which sends the marking current, but by the *next but two;* that is to say, the first tooth being positive, causes the armature to be attracted; the second, which is negative, does not act, nor does the third, which is

positive, there being no holes in the paper over them; but there is a hole over the fourth tooth, which, being negative, reverses the current. A second and parallel line of holes is punched in the sending ribbon, forming a kind of rack to receive the teeth of a wheel which carries the paper forward; this secures accurate coincidence between the perforations and the divisions of the wheel over which the paper runs.

It would however appear that the system of making contact through slits or perforations is not perfect; the contacts are apt to be interfered with by dust and the fibres of the paper itself, and the duration of the contacts is shortened by the brush or spring being compelled to drop through the band and to be lifted again by the edges of the perforations. So much is this the case, that a much better result is obtained by lengthening the perforations, and increasing the speed of the band in a corresponding degree.

409. Wheatstone has avoided this defect completely. In his system the contacts are made, as in a key or relay, between platinum levers or pins, and the paper band simply regulates the movement of these contact pieces, in the same manner as the cards of a Jacquard loom determine the lifting of the threads of the warp.

The apparatus, as originally arranged, produced, like Siemens's, dots by a positive current followed immediately by a negative of the same duration and strength, and dashes, by a similar pair of currents separated by an interval during which the wire was insulated at the sending end.

This system, though it produced a higher speed of signalling than had heretofore been attained, was not perfect. Certain letters and combinations of letters failed at a rate of transmission varying with the condition of the line, and especially with the position in the circuit of buried wires or of cables. At high speeds the effect of induction is evident even on suspended wires, and sometimes land lines work faster in damp than in very fine dry weather.

Dots at the commencement of a message are lengthened so as to run into the following dash, and when they follow a dash they are shortened or lost. Thus in sending an alphabet the A (- —) becomes a T (—), and the N (— -) becomes T E (– ·). If a series of alphabets are signalled, it is found that the shorter the interval between the letters, the more rapidly can they be produced.

When a cable, say 120 miles long, is placed between two land lines A and B, of 20 and 130 miles respectively, the rate of transmission from A to B is considerably higher than in a reverse direction, in fact about as 9 to 6; and although the ordinary effect of an increase in the resistance of a land wire is to decrease speed, it will be found that when short currents followed by insulation of the sending end of the wire are used, as in this apparatus, the speed from A to B is increased by employing a wire for line B of No. 8 gauge in place of a No. 4. But in speaking from B to A, the thicker wire will give the best results.

That is to say, the line between the battery and the cable should be decreased in resistance, the battery itself having as low a resistance as possible, while, on the other hand, the resistance of the line between the cable and the receiving instrument should be increased. In the case under consideration as much as five thousand ohms may be inserted at the receiving end with advantage, that is to say, a resistance considerably greater than that of the rest of the circuit; the object being to secure a high and uniform potential in the cable, and for this purpose to prevent its discharging itself too quickly at the distant end. This gives a heavier mark and a greater range of adjustment of the receiving instrument.

But when the land line B is increased to 300 miles, and the cable is reduced to 60 miles, A remaining unaltered, the addition of resistance to A, when A receives, does not produce the same effect; for the potential of the end of the cable adjoining line B cannot be raised so high as in the case of the

shorter land line. Here the speed from B to A is only about one-half that in the reverse direction, or about 40 and 80 words per minute respectively.

In addition to the compensation for loss to earth by the addition of resistance at the receiving end, it is necessary to compensate for the irregularity of *interval* between the positive and negative currents (irregularity of *duration* having been avoided by the system of equal current or dots), so that the potential of the wire may be kept as nearly uniform as possible at the commencement of each signal. This is effected by an arrangement of the apparatus by which weak currents are sent in the intervals during which under the original system the wire was disconnected; so that the first and last current of a dot or dash pass to line direct, and the interpolated or compensating currents pass to line through a high resistance, which can be varied at will to increase or diminish the strength of the currents. A further increase of speed is obtained by placing a condenser between the line and the receiving instrument, the plates being connected or shunted by a high resistance. A condenser at the sending end lowers speed by causing the marks to run together.

By *speed* is here meant the number of *perfectly formed* signals which can be produced in a given time, not the actual rate at which *waves* can be produced. With this apparatus speed is inversely as the distance, not as the square of the distance.

The manner in which the currents are produced, with their order of sequence and strength, are shown in the description of the *transmitter*. Much still remains to be done, and a more perfect system of compensation is needed. In land lines where there is much buried wire the system just described is employed, and as a very feeble "contact" or leakage from wire to wire affects the delicate apparatus, it is frequently advantageous to introduce resistance at the receiving end to decrease the tendency to the admission of false currents.

The following is a description of the different instruments which constitute Sir C. Wheatstone's automatic system, as it is at present employed by the Post Office in its telegraphic correspondence between London and the principal cities of the empire.

The paper ribbon is prepared by an instrument containing three levers, one of which produces two holes at right angles to the paper for a dot, another two holes diagonally for a dash, and a third smaller holes in the centre of the ribbon, forming a *rack* by which the paper is carried forward in the transmission of a message. The dot and the dash punch act also upon the third or centre punch. They are either struck with a small mallet or by pistons actuated by compressed air. In the latter case the punching is performed by means of three keys, whose touch is as light as those of a pianoforte.

The Transmitter is driven by a weight, and its speed can be adjusted between 20 and 120 words a minute. The perforated paper is carried forward by the teeth of a star-wheel driven by the wheelwork engaging the centre row of holes in the ribbon, and is kept in close contact with the star-wheel by the slotted friction roller W (Fig. 1).

An ebonite rocking beam R, moved by the clockwork, carries three pins: that on the left hand is connected to Line, that on the right to Earth; the centre pin is insulated, and serves to connect the lever B with one or other of the levers Z or C, according to the position of the rocking beam.

Under the beam lie the levers A and B, pivoted independently, but in electrical connection through the spiral springs H H′ and the frame of the instrument.

On the ends of A and B are pivoted the vertical needles V V′; the first regulates the production of the marking, the last that of the reverse current. These levers are not *fixed* to any of the moving parts of the apparatus, but are simply pressed upwards by the spiral springs H H′, so as to follow the move-

ments of the rocking beam, and remain in contact with the pins inserted into this beam so long as their upward movements are unchecked.

The needles attached to these levers determine whether line-contact shall be made or broken at the moment battery-contact is made; they rise alternately until they touch the paper ribbon: if there be a hole opposite their points they pass through it, and the contact is undisturbed; but should there not be a hole their motion and that of the lever is stopped, and the peg on the rocking beam continuing to rise, contact is broken between it and the lever.

Fig. 2, Plate I. shows the apparatus in position for sending a marking current. The levers Z C are the poles of the battery, copper is connected to line thus:—The lever C touches the centre pin on the rocking beam, lever B is also at the same moment in contact with the same pin: the current then passes by it from C to B, thence through the springs H H′ to lever A, and out to line through the left-hand pin on the rocking beam. Zinc is connected to earth by the lever Z, which touches the right-hand pin. The upward movement of the needle connected with B has in this case not been checked, so that the contact between the pins and levers has remained unbroken.

Fig. 3 shows the position for sending the reversal: Fig. 1 the manner in which the receiver, transmitter, and switch are connected, the switch being used to throw the line wire and batteries either to the sending or the receiving portion of the apparatus. It is shown in the position for sending. The black insulated pin I prevents the batteries being put on short circuit.

Figs. 1 and 2, Plate II. show the positions when the direct circuit is broken and the compensating current is sent through resistance. In Fig. 1 the rising of the lever B is prevented by the paper, the needle V not meeting with a hole in the ribbon. Here contact between the levers C and B is broken, because the centre pin in the beam touches the former only. The stop F is

in metallic connection with lever C; the piece N, which is connected to the resistance coil, rests upon F, and the positive current is free to pass through the resistance coils to line.

Fig. 2 shows the negative current passing through resistance to line. Here the needle V′ is stopped by the paper preventing the lever A following an upward motion of the left-hand pin of the beam. The piece N now rests upon G, which is connected to zinc.

The movements of N are regulated by the rods D, E, which, assisted by the spring and roller S, cause it to spring over with a jerk and remain firmly in its place.

The transmitter may be arranged in three ways:—

(1.) To work with compensation currents, as has already been explained.

(2.) Without these currents, by taking out the infinite peg of the resistance coils, or by disconnecting them.

(3.) To work as a double current key, using two sets of batteries, putting the zinc of the one and the copper of the other to earth, disconnecting the earth wire from the transmitter and key. These currents may either be compensated or not, at will.

The Receiver.—Fig. 3, Plate II. shows the electro-magnet, and its coils, with the adjusting chain. The system of writing is peculiar; a very light inking disc, actuated by the moveable magnet, and kept in motion by the maintaining power of the instrument, presses against the paper slip, and takes its ink from the groove of a larger disc, which is also kept in motion by the maintaining power; this disc dips into a reservoir of ink, and its groove being supplied by capillary attraction, the smaller disc takes its supply from the larger one, without any friction against it. The writing is in the ordinary Morse code.

Plate II. Fig. 5, shows the ribbon punched for the letters A, I, T, and the letters themselves as received in the Morse code. To produce these letters the *transmitter* performs the following movements:—

(*a*) The needle V passes through the first hole in the *upper* row, and a copper current is sent to line (Plate I. Fig. 2). This is the commencement of the dot.

(*b*) The needle V′ passes through the first hole in the *lower row*, sending a zinc current to line (Plate I. Fig. 3). This current causes the inking disc to be removed from the paper and completes the dot.

(*c*) The needle V passes through the second hole in the upper row, and a copper marking current is again sent to line, causing the inking disc to commence the dash.

(*d*) V′ is next brought in contact with the paper, but cannot pass through it. The circuit is now broken, and no current can flow through the resistance coils, because the piece N still remains in the position in which it was placed by the first movement (Plate I. Fig. 2), not having been pushed over by the horizontal rod E, as it would have been if the lever A had not been prevented rising. This position is not shown in the diagram, but N may be conceived resting against F instead of G in the diagram (Fig. 2, Plate II.). The line is put to earth through the resistance; this is not intentional, but consequent upon the present form of the apparatus.

(*e*) The next movement is that shown in Plate II. Fig. 1, where the needle V having been stopped by the paper, a copper compensating current passes to line through the resistance coils; the piece N still remaining where it was placed by the first movement for the dash, is now in position for allowing a current to pass through the resistance coils. This weakened copper current between the commencing and closing currents of the dash keeps the potential of the line uniform.

(*f*) The last movement for the dash is shown in Plate I. Fig. 3, and is similar to the last movement for the dot. N is now pushed over to the other side, against the stop G.

(*g*) In the space which follows, the same movements occur as between the first and last currents of the dash. Fig. 5, Plate II. shows this sequence of currents.

The receiver can, like the transmitter, be regulated for speed, and it is furnished with an adjustment for the magnet shown in Fig. 3, Plate II.

A double current Morse key is connected in circuit for hand-signalling. An average throughout the day of 100 messages per hour have been sent by this over a line of 200 miles.

GENERAL REMARKS AS TO THE MANAGEMENT OF CIRCUITS.

410. *The longer the line the better the insulation required.*—A very inferior insulator suffices for a short line of but few instruments, but if there be many instruments in circuit the insulation should be improved.

The greater the number of wires, the better should be the insulation.

It is impossible to insulate a long line too well. It must be remembered that an efficient telegraph is one which works well in all states of weather, and consequently the insulation must be adapted for the worst weather, not to the average.

411. When insulation is bad and cannot be improved, the resistance of the battery should be lessened by using large plates, or connecting two or more in series, side by side.

The resistance of the apparatus may also be lessened, and this may also be done with advantage when there are a large number of instruments in circuit.

It sometimes happens that a dozen needle instruments, or even more, are placed upon a line of 30 miles or less. Now, the resistance of 30 miles of No. 8 wire is, say, 400 ohms, while that of twelve ordinary needle instruments is 1820 ohms. In such a case an advantage has been gained by winding the coils of the intermediate instruments with a thicker wire, so as to reduce

their resistance to 420. But on account of the leakage in wet weather, it has always been necessary to place coils of the higher resistance, say of 152 ohms, at the terminal stations.

412. On a long line, apparatus having coils of considerable resistance is used in order to multiply the effect of the current; but when there are several stations in the circuit, the apparatus resistance exceeds that of the line, and again demands a battery of greater tension and of greater resistance to overcome it. In fine weather the inconvenience is not felt, because there is then no difficulty in obtaining good signals with even a very small number of cells, and the ordinary working power is always much more than sufficient. But in wet weather great advantage is felt from reducing the resistance of the intermediate instruments. It is obvious that when leakage exists the current will always be more powerful at any one of the intermediate stations than at the two ends, because the derived circuits virtually shorten the line.

A method has lately been tried which promises good results. Instead of using coils of fewer convolutions and of less resistance at the intermediate stations, a shunt is placed across these coils to divert a portion of the current from them, and thus, by reducing the resistance of the circuit, to produce a stronger signal at the terminal station.

It may be asked whether a better result would not be obtained by winding the coils with a thicker wire, but it seems that even though the resistance be reduced to $\frac{1}{10}$th by a shunt, it may yet give readable signals; which a coil of a reduced number of convolutions would not do even if its resistance were lowered only to a fourth part of the original resistance; because in the case of the shunted coil the small portion of the current multiplied by the large number of turns of the wire has a better effect than the larger portion multiplied to a less degree. And, moreover, as a very feeble signal is sufficient to indicate a "call" where the person in charge is attentive, the coils may be shunted so low that the call is just visible, when the resistance of the line will be at its minimum, and the more distant stations will be benefited to

the utmost. When a call is observed, sufficient current may be admitted to allow the message to be read, and the coil again shunted for the advantage of the more distant stations.

413. When insulation is very defective and there is much contact, it is not desirable to use too sensitive an instrument upon the shorter circuits on the poles. As a last resource the coils of the needle instrument may be opened, that their action on the needle may be so far lessened as to render it insensible to the leakage from the longer circuits, and the battery power may be a little increased to make up for the want of sensitiveness.

Insulation may be temporarily improved by washing with paraffin oil.

Insulation is more important near the extremities than in the centre of a circuit.

When wires run through districts exposed to excessive rain or to salt spray, so that insulation is well nigh impossible, a larger wire should be used. In some parts of India an iron rod is used fixed to wood supports, and with advantage; the great conducting power of the rod making up for the deficiency in insulation.

A faulty wire is much more effectively worked upon the double-current system, than by single or unreversed currents; consequently the Morse or sounder is more suitable for such a circuit than the bell or the modified (two line) printing system.

In working such a line, the signals should be made *firmly*, so as to lengthen the battery contacts. A key so constructed as to do this mechanically may be found advantageous.

The closed circuit or permanent current system is very much affected by weather, and seems adapted only for well-insulated lines of few instruments.

A key sometimes fails from the earth contact not being fairly broken before the line contact is established.

A dirty key will frequently send a current on short circuit, but not on the line. This happens when the resistance of the line, added to that of the key, is too great for the current to overcome. The current burns or hardens the oil used on the pivots, and if

too much oil is used on the key it becomes mixed with metal-dust and dirt, so as to coat over the insulated parts.

When communication is interrupted, the sending batteries and apparatus should be tested on *short circuit* by connecting together the terminals leading to earth and line, or up and down line respectively, and moving the key. If the batteries, key, and connections, be in order, the machine should move; for the line is now cut out of circuit, and is replaced by the wire used to put the apparatus on short circuit.

In sending, attention should always be paid to the galvanometer, in order to ascertain whether the current passes out to the line. A clerk should always be able to estimate the sensitiveness of his galvanometer, and to know whether the current which passes through it is weaker or stronger than usual. If weaker, the fault may be in his sending batteries; there may be a disconnection, or partial disconnection, on the line, or a defective point of contact in his key: if much stronger than usual, the fault will be earth on line: if extremely strong, the cause will be earth near his station, or perhaps in the office.

414. *Forked Circuits.*—It is often necessary to place in circuit three stations, whose line wires radiate from a common centre in the manner of the portions of the letter Y. Let the station at the foot of the Y be A, the upper right-hand station B, the upper left-hand C, and the point where the three lines meet D. In the ordinary method, either C or B would be placed in a loop of two wires. But if the resistances of the arms B and C do not materially differ, the circuit may be forked or bifurcated at D. If relays with soft iron armatures are used, so that the instruments are actuated in the same direction with either positive or negative currents, no special arrangements will be necessary; but if polarized relays or needle instruments be employed, it will be necessary to fix a switch for reversing line, earth, and batteries at either B or C.

Let the switch be fixed at B: its normal position should be such that the instrument at B is connected up similarly to that

at C, so that the signals from A, which would split or divide at D, may pass through B and C in the same direction. A can then speak either to B or C, and *vice versâ*; but B cannot speak to C, because the instruments at those two stations are not joined up according to the rules laid down for needle instruments in paragraph 359. But if the line and earth can be reversed by the switch at B, the currents will pass through B's coils in the right direction. The switch being arranged so as to reverse the batteries at the same time, B's current will now be in the proper direction to speak to C, but will be reversed at A. This is of no importance.

It will readily be seen that if it be arranged to "call" B by a given signal, that station will know that when the "call" is reversed the switch must be turned.

415. *Transmission to several stations simultaneously.*—It often happens that intelligence is required to be transmitted to a considerable number of stations, and it is obviously desirable that as many as possible should read it at the same time. With ordinary care and attention on the part of the clerks, six or more can readily read the same despatch, if their instruments are in circuit together. If two lines branch or fork off at the intermediate station D, a translator or repeater can be placed there in the wire leading from A to C; the current from A will pass through this instrument to C direct, and will be relayed on to B by the repeater at D. The original current might be *forked* to C and B, as shown in the preceding paragraph; but the signals are more certain under the system of translation, because they are not affected by a variation in the relative insulation, or in the resistances of the several branches.

By means of a combination of the automatic system with that just described, the same perforated paper is made to transmit newspaper messages to several groups of six, or even more stations. The transmitting apparatus are arranged side by side, and the ribbon passes through each in succession.

PART X.

UNDERGROUND AND SUBMARINE TELEGRAPHS.

416. THE testing of submarine, and even of long underground lines, demands far more electrical knowledge and much greater care than is necessary for overground wires. The principal apparatus used are the differential galvanometer and resistance coils or rheostat, which have already been described: the Wheatstone balance, the Peltier and the Thomson electrometer, and the Thomson or some other delicate galvanometer.

417. THE WHEATSTONE BALANCE OR PARALLELOGRAM.—When one pole of a battery is put to earth, and the other pole so connected to a long wire E F that a current flows through it from

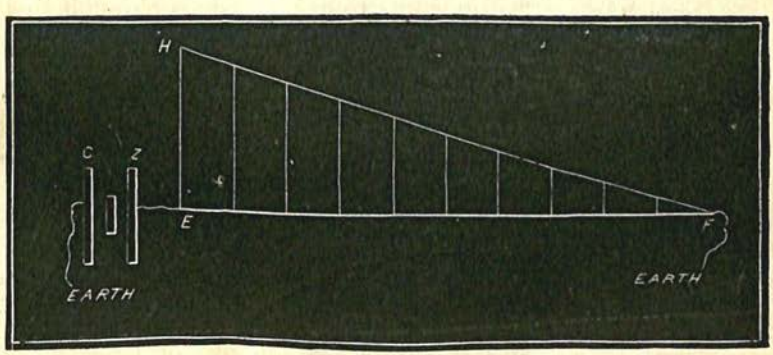


FIG. 105.

battery to earth, as shown in Fig. 105; the tension in the wire E F will fall regularly from a maximum at E to zero at

F, and if the perpendicular H E represents the tension at E, the perpendiculars or ordinates at the succeeding points will represent the tensions at those points, as may be proved by the electrometer.

It is convenient in describing the balance to use the well-known parallelogram, although in practice the apparatus never bears this form. The figure is readily borne in mind, and is a great assistance both in comprehending the principle involved and in arranging the connections for a test.

The principle is perhaps more readily understood if it be supposed that one pole of the battery, say the copper pole, is put to earth: let it, then, be imagined that this has been done, although it is not necessary.

Let, then, the copper pole be put to earth, and let the wire E F be divided into two equal branches, A B, C D; and from the

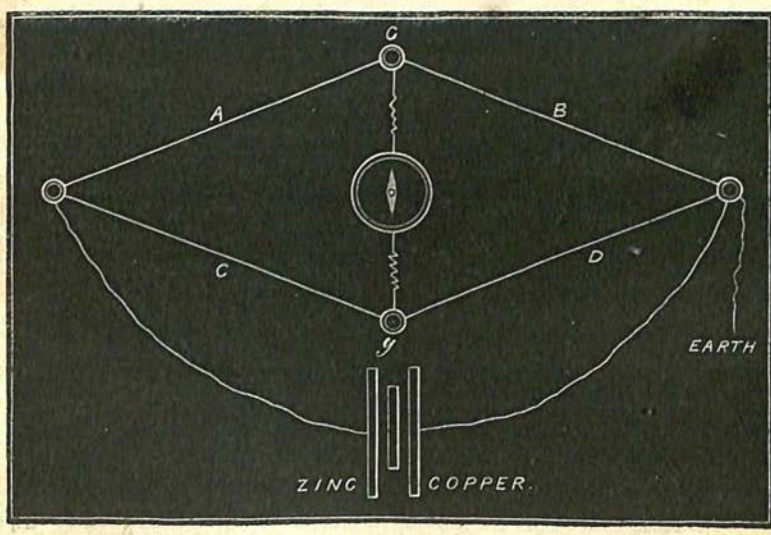


FIG. 106.

centre of one branch to the centre of the other make a cross connection G *g*, containing a delicate galvanometer.

The tension in each branch will fall uniformly from the end

which is connected to the zinc to that connected to the copper, and will therefore be *equal* at any two points equally distant, *in resistance*, from the zinc end, as at A and C, G and *g*, or B and D. As a current is caused by a *difference* of tensions, and cannot exist between points having the same tension, no current will pass through the galvanometer connecting G and *g*, however powerful a battery may be used.

Again, when A bears the same *proportion* to C that B does to D, or when A : C : : B : D, no current will pass between G and *g*. For, let the resistance of the arm A be made 10, that of B 1, of C 1,000, and of D 100, the total resistance of the branch A B will now be 11, and that of C D 1,100; but the tension in each branch will have fallen *in the same proportion*, or to the *same fraction* of its maximum ($\frac{1}{11}$ths) at the points G and *g*, and the tension at G will therefore be equal to the tension at *g*.

In using the balance, the cable or other object to be measured is placed in the branch D, and resistance coils in B. If the cable resistance is within the range of the resistance coils at B, then A and C are made equal, and the resistance of B adjusted until the needle remains steadily at zero, when battery contact is made and broken.[1] When the resistance at B is too great, the needle will move; when too small it also moves, but in the opposite direction; remaining unmoved only when B has been made exactly equal to D.

The resistance of the cable will in this case equal that of the coils at B, for A : C : : B : D; and A and C being equal, B and D must be equal also.

To measure a resistance *greater* than that of the coils at B, the resistance of A is made *less* than that of C, and the reading at B is multiplied by the ratio between them. Let A be made 1

[1] A very feeble force frequently repeated will set a needle swinging, when the movement caused by a single contact is imperceptible; but care must be taken to make the contacts coincide with the swing of the needle, so as to assist it.

and C 1,000, or let them be in the proportion of 1 to 1,000, and let the reading at B be 2,000; then A : C : : B : D or 1 : 1,000 : : 2,000 : two millions, the resistance of the cable. Conversely, when the resistance to be tested is *less* than can be measured by the coils at B, A is made *greater* than C; thus, let A be 100 and C 10, or in the proportion of 10 to 1, and let the reading at B be 1, then A : C : : B : D or 100 : 10 : : 1 : 0·1. Thus the resistances of A and C may be varied at pleasure, until they bear such a ratio one to the other as will enable the coils at B to balance the cable at D, when the resistance is found by direct rule of three.

The galvanometer need not be graduated, but the needle must be very freely suspended. A key is placed at *g*, to cut the galvanometer out of circuit when desired; this serves to prevent too powerful a current, such as the charge of a cable passing through the coils, and is especially useful in cable testing.

A key is also placed in the battery wire, to put the battery in or out of circuit.

It is always necessary that some resistance should be placed in A and C, or the tensions at G and *g* would be equal to each other, however much the resistances of B and D might vary; and the greater the resistance to be measured, the greater should be the resistance placed in A and C. This resistance may be formed of two perfectly equal wires wound together upon a bobbin and cased in paraffin, or the two wires may bear a ratio one to the other of 1 to 10, 1 to 100, or 1 to 1,000. In testing short lengths great care must be taken not to allow the resistance coils to become heated, and for this reason the battery current must not be applied too long.

In practice the arms A and C are formed of a set of resistance coils, which may be supposed to be placed between *a'* and *c'*, the connection with Z being made by a wire attached to one of the plugs of the coils. The two extremities of the coils are connected to the galvanometer, as at G and *g*, respectively. The posi-

tion of the plug in the resistance coils can then be altered, until the required proportion between the arms A and C has been obtained.

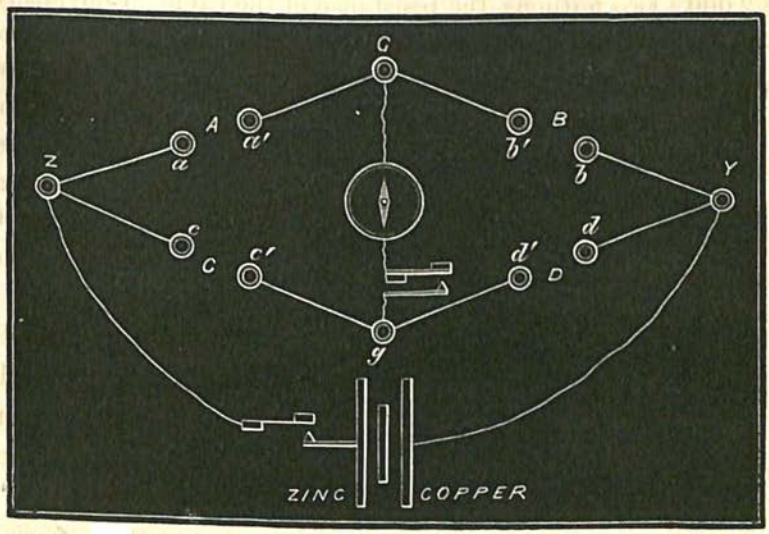


FIG. 107.

The wires forming the parallelogram (Fig. 107) are supposed to have no resistance whatever.

Resistance coils should be wound half in one direction, and half in the reverse direction, to avoid the induction of the current upon itself, which may interfere with the test.

418. THE ELECTROMETER OF MILNER OR PELTIER consists of a light wire, generally of aluminium, pivoted by a polished steel cap upon a fine point. All the parts are in metallic connection with each other, but insulated from the base board. A fragment of a sewing-needle magnetized is fixed to the moveable wire, to cause it to regain its position after having been deflected. To adjust the instrument, it is turned round until the wire lies parallel to the horizontal rod. The insulated wire to be tested is attached to the knob. It is charged by a spark; or by being touched with a wire connected to a battery of 100 cells or more; the wire of the electrometer will be repelled by the rod, and its

deflection may be read off upon a graduated scale. A mirror is generally placed below the scale, and in reading off, the moveable wire and its deflection are *brought into one*, or made to coincide. As the charge escapes from the wire under test, the divergence of the electrometer will gradually decrease.

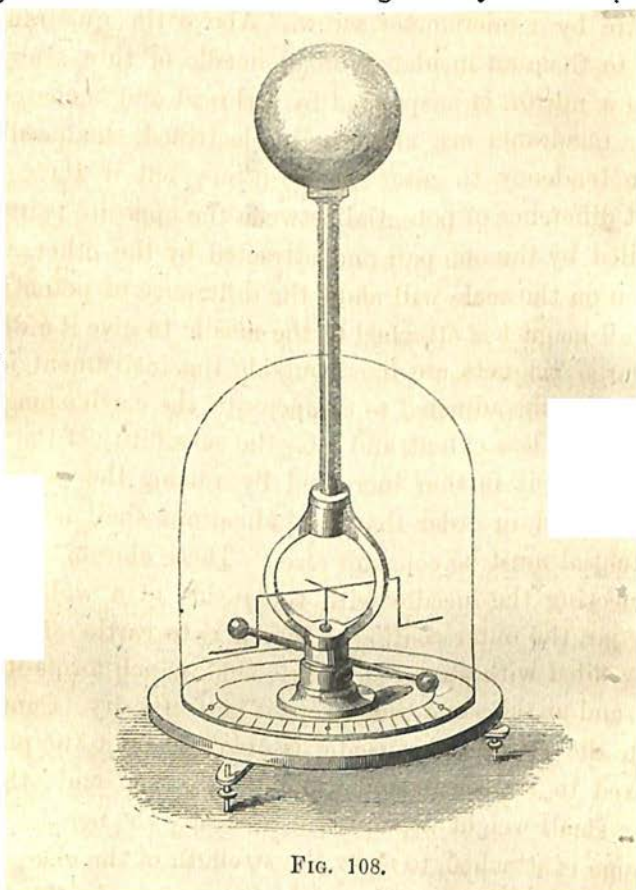


FIG. 108.

The apparatus must be very perfectly insulated, but there will always be some loss, the amount of which must be ascertained, and allowed for. The interior can be kept dry by placing in it a saucer containing chloride of calcium. The electrometer is sometimes surrounded by a wire cage connected to earth, to cut off exterior induction.

419. THOMSON'S REFLECTING ELECTROMETER.—This instrument is fully described in the report of the standards committee of the British Association for 1867.

A polished brass disc is divided into four quadrants, arranged in a horizontal plane, one of which can be moved outwards from the centre by a micrometer screw. Above the quadrants and parallel to them an insulated broad needle of thin aluminium carrying a mirror, is suspended by a thread and is charged. If the four quadrants are all equally electrified, the needle will have no tendency to alter its position; but if there be the slightest difference of potential between the opposite pairs it will be repelled by the one pair and attracted by the other, and the deflection on the scale will show the difference of potential. A very small magnet is attached to the needle to give it a directive force; large magnets are fixed outside the instrument, and are capable of being adjusted to compensate the earth's magnetism to a greater or less extent, and alter the sensibility of the needle. Its sensibility is further increased by raising the potential of the needle, and, in order that its indications shall be constant, this potential must be constant also. These objects are effected by connecting the needle with the inside of a well-insulated Leyden jar, the outer coating of which is to earth. This jar is partially filled with strong sulphuric acid, which forms its inner coating, and at the same time keeps it perfectly dry. Connection between the jar and the needle is obtained by a fine platinum wire fixed to its centre and dipping into the acid; the wire carries a small weight which tends to steady the needle.

A gauge is attached, to show the strength of the charge of the jar; it is a little electrical weighbridge, showing the force of attraction between two parallel plates. A revolving "doubler" is provided for the purpose of increasing or lessening the charge of the jar, so as to keep its potential uniform; the doubler acts somewhat on the principle of Holtz's electrical machine. Another check upon the constancy of the apparatus is afforded by the

moveable quadrant. If all else is constant—the force of the magnets and the charge of the jar—a certain number of turns of the micrometer screw will produce in every case the same deflection of the spot of light. This electrometer may be adjusted so as to show a difference of potential as small as the tenth part of the tension of a single Daniell cell.

420. THOMSON'S REFLECTING GALVANOMETER has circular coils, in the centre of which a very light magnet, carrying a mirror, is suspended by a silk thread. A scale of equal parts is placed two or three feet from the mirror; a narrow slit is cut in the centre of the scale to allow a ray of light to shine upon the mirror from a lamp placed behind it. This ray is reflected back upon the scale, and is the index of the galvanometer; the angle through which the ray moves is double that traversed by the mirror, and it is therefore really equivalent to an index four or six feet in length, *without weight.* When the scale is three feet from the mirror, each degree of deflection moves the spot of light more than an inch. The great length of the index thus renders the slightest movement of the mirror perceptible, and as its deviation never exceeds 10°, the divisions of the scale accurately represent the force of the current. It is not only a most accurate, but a most convenient instrument.

UNDERGROUND AND TUNNEL WORK.

421. Percha wire intended to be placed underground, or in tunnels, should be carefully tested by a delicate galvanometer for insulation, then covered with tape soaked in *Stockholm* tar, and sanded.

It should also be tested for continuity or resistance before it is used. It is not often that continuity fails, but now and then a wire will be broken inside the gutta-percha.

It is useless to test for insulation *until the wire has been soaked in water twelve hours*, to give the water time to enter any small pinhole or crack which may exist. A small fault, if allowed to remain, will increase, and ultimately spoil the wire. So important is perfect insulation that a battery of 250 cells, and a very delicate horizontal galvanometer, should be used for these tests.

422. The wire may be tested for insulation by ascertaining if it will retain a *charge*. Put one pole of a battery of not fewer than 50 cells to earth, and with the other pole touch one end of the wire for a moment, leaving the other end disconnected. After, say 30 seconds, put the wire to earth through a galvanometer, when the charge will pass to earth, moving the needle. If a galvanometer be not at hand, the charge may be taken on the tongue with equal certainty as to the result, and without any inconvenience from lengths under a mile. This is a very good rough test.

423. A more accurate test may be made by the Peltier electrometer (418). Dry both ends of the covering and wash them with paraffin oil, or for very delicate tests coat them with solid paraffin. Connect one end of the wire to the electrometer, leaving the other free, and charge the wire by the battery as before; the needle will diverge, gradually falling back to zero as the charge escapes. The time occupied in the falling of the tension one-half is taken as the measure of insulation. A new wire of No. 18 gauge, covered with percha to No. 7 gauge, should not lose its charge in less than 10 minutes, at 50° Fahr.

But the graduation of this instrument, like that of the horizontal galvanometer (122), is not accurate, and for the same reason. It is, therefore, always necessary to ascertain by trial what angle of deflection represents one-half the tension. Divide the battery into two equal parts, charge the wire by each in turn, and take the mean.

424. When the wire proves defective, the fault, if not very

minute, may be found by running it through water, connecting one pole of a battery of not less than 40 cells with a good galvanometer, the galvanometer with the wire, and the other pole of the battery with the water; when the fault touches the water the needle will move. Or the wet wire may be run through the hand, when a shock will be felt as the fault passes.

425. To find a fault in a very highly insulating sheathing covered with a good conductor, Hooper's material for instance, the coil is wound upon two insulated reels set several feet apart, the tape is carefully removed over a space of six inches and the rubber washed with naptha or paraffin oil, so as to insulate the two portions of the wire one from the other. The ends are prepared by paring and coating with paraffin to prevent surface conduction, one is left free, the other is connected to an ordinary electrometer.

The two drums are next connected to earth, and the conducting wire charged from a battery or electrical machine in the manner of a Leyden jar. The earth wire is now removed from one of the drums, but left in contact with the other; the deflection of the electrometer noted to ascertain the loss by leakage in a given time. The connections are now altered so as to give a similar test to the portion of the coil on the other reel, and a comparison of the loss from each shows which of the two contains the fault. The drum containing the fault will obviously lose its charge by leakage when its outer coating is connected to earth, but retain it so long as the outer coating remains insulated, so that if the conditions of the two are reversed the electrometer will show which of them contains the fault.

The faulty portion is then partially wound upon the drum containing the sound portion, the coating again removed between the two and tested in the same manner. The process is repeated until the exact spot is found. A very minute defect can be detected by this method.

426. In all tests of covered wire, the copper pole of the

battery should be put to earth, so as to send a negative or zinc current to the wire; for positive currents have a tendency to lessen a fault, negative currents to increase it. The copper current oxidizes the bare part of the wire, and coats it with an imperfect conductor, while the zinc current reduces any metallic salts that may have been formed, and, as it were, electrotypes a clean surface.

Thus, an underground wire which seems perfect if tested with a copper current, will sometimes show a large amount of earth when a zinc current is used.

427. When a wire is too defective to be used, while the fault is too small to be readily found by distance tests (350) it may be made worse by keeping a powerful zinc current upon it for several hours. And a bad wire may be made better for a time by a copper current, care being taken, if reversed currents are employed in signalling, that the zinc or reverse current shall be much feebler than the copper or sending current; the copper current will, however, eat away the wire sooner or later.

428. In tunnels, if a fault in the covering is exposed to dropping water charged with salts of lime, the wire is frequently dissolved away for a quarter of an inch or more, the current still passing by the conducting power of the solution of copper: hence such a wire works best in wet weather. In percha-covered wire which has lain ten or fourteen years under the street, near a gas-pipe, the copper has been entirely converted into sulphite by the gas liquid. Iron wires, in tunnels through limestone rock, are sometimes corroded by drippings of water holding lime in solution. In a tunnel near Haddon Hall, in Derbyshire, the drippings have been found to contain free sulphuric acid.

429. In a tunnel the place of a fault may be found thus:— Put a current of 40 cells, or more, upon the wire at the mouth of the tunnel, disconnecting the other end. Wrap one bare end of a piece of covered wire with wet cotton waste, and connect

the other to a detector in connection with the rail. Run the waste along the tunnel wire, carrying the detector forward until the needle is deflected by the current escaping through the waste at the fault. The detector may be fixed to a staff ending in an iron point, which can be set upon the rails, which should be moistened to make good earth. If the fault is large, or the battery strong, it may be *felt* by holding the wet waste in the hand, and running it over the wire. The wire may also be cut and tested in sections for earth.

430. It is not possible to pick out a wire from among a a number in underground or tunnel work, except at the places where they are labelled. In order to find a wire, a current is sometimes sent through it from a battery having one pole to earth, and each wire is cut or pricked with a knife in succession until one is found which causes the deflection of a detector placed between the knife and earth, which is the wire sought. A great objection to this method is that it is difficult to insure the perfect sealing up of the incisions, so that faults are produced which develop themselves in course of time.

An instrument called a *wire-finder* enables any one of a number of wires to be picked out without cutting the covering. An astatic pair of needles is hung upon a hair in a box having a groove in its side, into which the wires can be placed one by one. The needles are connected by a curved bar, so that one hangs above and one below the groove, and consequently if a wire conveying a current is placed in the groove, the needles are deflected. A modification of this apparatus is a single suspended horizontal needle, directed by a bar magnet (125) so as to stand in any required position with regard to the meridian. This is placed above the wires in such a position that they can be lifted under the box containing the needle. The former instrument is the more sensitive, the latter is perhaps the more easy to manage. A little practice will enable an ordinary workman to use either of them.

Where there are wires among the number conveying permanent currents, the direction of the testing current must be opposite to that of the permanent current, and the direction in which the instrument will be deflected by each must be ascertained beforehand.

431. Covered wires may be worked if hung upon hooks driven into the walls of a tunnel, when they are too defective for use when lying in a trough or pipe. If they are removed into the open air, dried, tarred separately, and made into a cable wrapped with tarred canvas, they will last several years. When hooks are used to suspend a cable, it must be carefully protected from chafing at the points of suspension.

432. In testing covered wire for faults, it is more convenient to use a small horizontal galvanometer than a vertical *detector*, for 10 cells with the former will be more effective than 50 with the latter, so that the trouble of carrying a large number of batteries will be avoided. When a tunnel, a leading in, or other piece of covered work is suspected to be faulty, it should be tested in *wet weather;* as a small fault which will impede communication after rain, will not be detected in dry weather, except by a very delicate apparatus.

In testing insulated wire, it is better to accustom workmen to use a galvanometer capable of showing a sensible deflection with a minute fault, for they seldom appreciate the fact that a very small deflection upon a rough and heavy galvanometer may indicate a considerable defect; but seem rather to consider that a leakage which does not produce a considerable effect upon their particular instrument, whatever it may be, is not important enough to be sought out.

433. When wires are made up into a bundle or cable, it is frequently necessary to number or label them at both ends after they are laid. A *detector* is placed at each end, a current is sent upon one of the wires through the detector from a battery connected to earth, and the distant ends of the wires are put to

earth through the second detector, one by one, until the wire conveying the current is found. Both detectors now deflect, and the person sending the current will know that the wire has been identified. The wire is now numbered *one*, and the current is sent on the second wire, and so on. It is better, to prevent mistakes, for the sender, when he sees the wire is found, to indicate its number by signal; and when there are many wires in the cable, a single-needle instrument may be used, to enable the parties to speak to each other if necessary.

SUBMARINE CABLES.

434. In planning a cable, the principal points for attention are—the form and strength of the sheath or outer covering; the insulation, which must be practically perfect, because a fault, however minute at first, will increase, and in time stop the communication; the inductive capacity and the conductivity, or conducting power, by which the speed of signalling, and consequently the commercial value of the cable, are determined. It is with the latter questions that we have now to deal.

The Copper Conducting Wire.

435. *Effect of increasing the purity of the copper.*—It has already been shown (158) that a cable forms a condenser or Leyden jar, of which the copper wire is the inner and the iron sheath the outer coating. Now, induction increases with the extent of the opposing surfaces of the condenser, and also with their degree of proximity or nearness. The tendency of an increase in the diameter of the copper wire is to increase its con-

ducting power, and therefore the speed of the cable; but as the surface of the conductor is increased at the same time, and the thickness of the percha decreased, there is greater induction, and, so far, a loss in speed.

But if it be possible to increase the conductivity of the copper without adding to its bulk, the inductive capacity of the cable remains unaltered, and the full advantage of the greater conducting power is obtained. This is effected by increasing the purity of the copper.

The attention which has been paid to this point is shown by the improvement which has been effected since the Malta-Alexandria cable was laid in 1861.

Taking the specific conductibility of pure copper as 100, the conductivity of the copper of the following cables are—

1861.	Malta-Alexandria	85·39
1866.	Lowestoft-Norderney	92·32
1865.	Atlantic	93·08
1866.	Do.	94·63
1869.	French Atlantic	94·90
1870.	West Indies and Panama . . .	96·16

436. The specification for the conductor of a cable states its weight per mile and percentage of conductivity. These points are carefully ascertained before the wire is covered with gutta-percha.

437. *To test the percentage of conductivity.*—Pure copper being taken as 100. Let 80 per cent. be the standard specified, for example; cut off 100 feet, ascertain that the diameter is correct, and weigh it carefully. Let the sample weigh 1,000 grains, or 10 grains per foot. Ascertain the temperature of the room (80), and refer to Table XII. for the specific resistance at that temperature of one foot of pure soft copper weighing one grain.

Let the temperature be 59° Fahr.

One *foot-grain* of pure soft wire at 59° has a specific resistance of	0·2186
[1] Add 25 per cent.—being the resistance of the sample in excess of the standard	0·0546
Then the resistance of 1 *foot-grain* of the required quality is	0·2732
And the resistance of 100 feet weighing 10 grains per foot	$\frac{0{\cdot}2732 \times 100}{10}$
	= 2·732 ohms.

If then the resistance of the sample of 100 feet does not exceed 2·7 ohms, the wire is of the desired quality.

438. *To find the specific conductivity.*—Cut off any convenient length, measure and weigh it. Let the length be 30 feet, weighing 300 grains, or 10 grains per foot, and let the resistance of the 30 feet be ·700 ohms, and the temperature 59° Fahr.

Find the resistance of a *foot-grain* of pure soft copper from Table XII. This will be found to be ·2186 for the temperature named. As the wire weighs 10 grains per foot, its resistance will be one-tenth of that of a *foot-grain*, and the 30 feet will have thirty times the resistance of 1 foot. Therefore,

$$\frac{{\cdot}2186 \times 30}{10} = {\cdot}655$$

would be the resistance of our 30 feet of wire if it were pure. But its actual resistance is ·700, and therefore by proportion

$$700 : 655 :: 100 : 93{\cdot}4.$$

93·4 is therefore the specific conductibility of the sample.

439. In all the tests the greatest care is required when short lengths are employed. The wire should not be stretched to

[1] Because the difference between 80 and 100 is 20, and 20 is 25 per cent. (or one-fourth) of 80. Or otherwise, the specific conductivity of pure copper is 100, and its resistance $\frac{1}{100}$, or ·0100. The specific conductivity of the sample being 80, resistance will be $\frac{1}{80}$, or ·0125, that is to say, 25 per cent. greater.

straighten it, but may be laid in a groove. It should be measured and tested before it is weighed, so that it may not be necessary to coil it.

440. *To find the resistance of a mile of wire.*—This can be found for any size or any temperature from Table XII.

Multiply the resistance of 1 foot at the given temperature by 5,280; this will be the resistance of 1 mile of wire weighing 1 grain per foot; call this r.

Then—As the weight (W) per mile in grains of the wire whose resistance (R) is required, is to the weight of one mile weighing 1 grain per foot (5,280 grains), so is the resistance r to the resistance required.

W : 5,280 : : r : R the resistance required.

Let it be required to find the resistance of a mile of hard copper wire ·030 in. diameter, at 16° Centigrade.

According to Table IX. the weight of a mile of copper wire, ·030 in. diam., is 14·26 lbs., or 99,820 grains.

The resistance of 1 foot weighing 1 grain will, at the given temperature, be ·2239 ohms; which, multiplied by 5,280, the number of feet in a mile, will give 1,182·2 as the resistance of a mile of wire weighing 1 grain per foot = r. Then—

99,820 : 5,280 : : 1,182·2 : 62·5,

the resistance of 1 mile of copper wire ·030 in. diam. at 16° Centigrade.

The resistance at this temperature of hard copper wire of any diameter may be found by dividing 6,242,016 (1,182 × 5,280) by the weight of grains in 1 mile of the wire whose resistance is required; or very nearly the same result may be obtained by dividing 892 by the number of lbs. in a mile.

A wire just drawn has a higher resistance than after it has been annealed; unequal or partial annealing will cause a considerable variation, and it is difficult to determine the precise hardness or softness of any specimen. Hence discrepancies cannot always be avoided.

441. *Method of joining wires.*—A solid wire is seldom used, a strand being more secure from breaking.

In connecting up two lengths of solid wire, each end is filed so as to form a *scarf* joint, which is well soldered with rosin, then bound or wrapped closely with fine wire, again soldered, and lastly re-wrapped with fine wire, soldered at each end only, so that it may pull out and keep up communication in case the joint stretches or breaks.

In joining a strand, the several wires are soldered together so as to form one solid wire, which is scarfed and treated in the manner already described.

The Insulator or Dielectric

442. The insulated wire of a submarine cable is technically called its *core,* and any piece of covered wire is frequently called a *cable* when speaking of testing.

For economical reasons the insulating covering is made as thin as possible, hence the value of a material depends, other things being equal, upon its high *conductive resistance,* or insulating power, and its low *inductive capacity,* the converse or reciprocal of which is its *inductive resistance.* India-rubber surpasses gutta-percha in both respects, but has failed to obtain confidence. A new preparation of rubber called "Hooper's material," and also vulcanised rubber, are considered likely to be lasting, but percha alone has as yet had an extended trial. Percha is practically indestructible when under water, and insulates well enough for all purposes at ordinary temperatures; but as it becomes soft, and also loses in great measure its insulating power, at about 100°, it is unsuitable for hot climates. Hooper's material will bear boiling without injury, and does not decrease in resistance with increase of temperature in so great a degree as percha.

443. *Tests applied to cables.*—As each coil of "core" is received from the factory, it is placed in a tank filled with water

at 75°, the standard for all tests affected by temperature, and after an immersion of 24 hours,[1] during which time the temperature is kept rigorously uniform, it is tested for the *resistance* of the conductor, for inductive capacity, or the power of becoming charged like a Leyden jar; and lastly, for insulation. It is usual to specify for a resistance of 200 million ohms per knot; but even in a core of 148 lbs. of percha and 107 lbs. of copper per knot, a resistance of 300 millions is easily obtained.

A freshly covered percha core improves sensibly in resistance for several days. The insulation test is generally taken fourteen days after manufacture.

The capacity test, compared with the conductivity test (or the test for the specific resistance of the conducting wire), shows if the copper be of the standard purity, and of the correct diameter or weight. For instance, it might be possible to use inferior copper, and to compensate for its lower conductibility by increasing its thickness; but this would in turn increase the inductive capacity, and cause the core to take a higher charge—unless indeed the percha were proportionally increased in thickness, which would scarcely be probable, because it would increase the size of the core, and therefore its cost.

The joints, where the several coils of core are connected, are tested for insulation by the accumulation process, which will shortly be explained, and the cable itself is constantly under test during its manufacture, so as to detect the minutest fault at the moment of its occurrence.

444. *Standard temperature for tests.*—As the resistance both of metals and insulators varies with temperature, it is necessary for the sake of comparison to fix a standard to which all tests shall be reduced. This standard is 75° Fahr., a temperature high enough to exaggerate faults in insulation, yet not so high as to injure the material.

[1] The reason for the long immersion of the core is that a change of temperatur affects the resistance of percha very slowly.

The reduction is effected by the co-efficients or multipliers given in Tables XIII., XV., the construction of which is explained at p. 342.

Suppose that the insulation resistance of a percha cable at 40° Fahr. be 300 megohms per knot, and it be required to reduce it to 75°. On referring to Table XV. the co-efficient for 40° will be found to be 13·116; that is to say, the resistance of percha is 13·116 times as great at 40° as it is at 75°. Dividing 300 by 13·116 we have 22·87, the resistance at 75°.

Again, if the resistance of a coil of copper wire be 1156·03 ohms at 60°, it is reduced to 75° in the following manner by the use of Table XIII. The difference between 60 and 75 is 15, and the co-efficient for 15 degrees is 1·03139, which multiplied by 1156·03 gives the resistance required.

445. In practice, the first test of the coils of core is the only one which is actually taken at 75°, all others are reduced to the standard by calculation. It is obviously impossible to heat the large tanks which contain finished cable, nor can their temperature always be correctly ascertained, because it varies in different parts. In such cases it may be found from the resistance of the copper wire, as will be explained in the Appendix; and, moreover, if we possess accurate data of the connection between resistance and temperature, we may even determine the temperature of the bottom of the sea in which a cable lies.

446. ELECTRIFICATION OR ABSORPTION.—When a core is tested, its insulation appears gradually to improve under the action of the battery, until after a certain interval it becomes sensibly constant, although the effect does not actually cease.

Further, if after battery contact has been broken, and the core discharged, it be allowed to remain insulated, several successive discharges can be obtained; especially when the testing current was powerful. This phenomenon is analogous to the so-called *residual charge* of a Leyden jar. Taking that view of conduction which supposes that each particle is polarized and transmits its

polarity to the next in succession, we know that this action will progress in a conductor with immense rapidity, and will cease as rapidly after the disturbing cause has been removed. The more imperfect the conductor the slower will the action be, until in an insulator (which may be considered as an extremely imperfect conductor, or a conductor of immense specific resistance) the polarization, and also the depolarization, will occupy a considerable time. The apparent excess of leakage during the first moments seems to arise from the current entering into and polarizing the gutta-percha; the first layer of particles is polarized in a comparatively short time, the next in a longer interval, and so on; the action becoming more and more difficult, and occupying a longer time, as layer after layer of particles is reached. The rush of electricity is, as it were, rapid at first, decreasing gradually until it almost ceases. After the battery is removed, the depolarization of the dielectric recharges the cable, so that a succession of discharges can be obtained.

So, in the Leyden jar, after it has apparently been completely discharged, we can, after an interval, obtain other small discharges due to the depolarization of the glass. The phenomenon varies in different insulating substances, and even in different samples of the same materials, and it is much more marked in rubber than in percha. Heat so far affects it that it proceeds more rapidly at a high than at a low temperature. The higher the tension of the battery, the higher the electrification.

The following table gives the leakage in degrees, taken upon a knot of core in the factory at 64° Fahr.; and shows the effect of electrification.

Leakage after	applying a current for	½	minute	430
Ditto	ditto	1	„	380
Ditto	ditto	2	„	350
Ditto	ditto	3	„	330
Ditto	ditto	4	„	320

Leakage after applying	a current for	5	minutes	315
Ditto	ditto	10	„	295
Ditto	ditto	15	„	278
Ditto	ditto	20	„	270
Ditto	ditto	25	„	265
Ditto	ditto	30	„	260
Ditto	ditto	35	„	255
Ditto	ditto	40	„	255
Ditto	ditto	50	„	250

447. *Standard interval* observed between the application of the battery and the taking the test. It is obvious from what has been said, that unless a definite time is allowed to elapse between the application of the battery and the reading the galvanometer, tests would not be comparable. The standard interval is *one minute.*

448. *Effect of pressure.* — A cable insulated with percha always improves in insulation after it has been laid, partly because the temperature is lower, and partly because of the pressure, which increases the resistance of percha between 2·3 and 2·6 per cent. for every 100 pounds on the square inch. It is said that the Atlantic Cable improved during submersion 7 per cent. for every 100 fathoms it sunk. In the factory, at 75°, the insulation was 390 million ohms per knot after one minute's electrification; when laid, 2,437 millions; and after 30 minutes' electrification, 7,000 millions. It is said that it now tests about 5,000 millions per knot.

Jenkin says (*N. B. Review*, Jan. 1867), "that the difference in conductibility between the percha of the Atlantic Cable and an equal bulk of copper, is as great as the difference between the velocity of light and that of a body moving but a foot in 6,700 years."

449. *Spontaneous charge* (so called).—If the conductor be allowed to remain insulated (*i.e.* disconnected from earth), it

becomes charged positively, spontaneously; and if it is discharged to earth through a galvanometer, a slight current passes to earth for several minutes.

The charge is directly proportional to the length of the wire, and increases as the time the core has remained insulated, up to a certain limit which has not been correctly ascertained. The same effect occurs in a condenser of tinfoil and paraffin paper.

As a cable is always tested with a negative current, and as the spontaneous charge is always positive, its discharge coincides in direction with the testing current; for a negative current entering the cable evidently passes in the same direction through the galvanometer as a positive current leaving the cable. As this or any other charge may affect both the insulation test and the test for inductive capacity, the conductor should always be connected to earth in the intervals of rest, so that it may be completely neutral.

450. *Test by deflection.*—When the leakage is comparatively great, the resistance may be measured directly by the balance or the differential galvanometer.

In even a moderately good core the leakage is much too small to be measurable by this method, and the following process is adopted, employing a sine or a Thomson galvanometer and 200 cells or more:—

(1.) Find the *constant* of the galvanometer, that is to say the deflection from *one* cell of the testing battery through a circuit of 1,000 ohms, the galvanometer being shunted (see Appendix) to the one-thousandth part. This will be equivalent to the deflection which would be obtained with one cell through one million ohms (1,000 ohms × 1,000th shunt). Let it be ten divisions or degrees of the galvanometer scale.

(2.) Find the tension of the whole battery in terms of the single cell used in taking the constant, by the formula which will presently be given.

This is necessary because it seldom happens that all the cells of a battery are alike in power; and therefore the real tension of, say, 100 cells may be less or more than one hundred times that of the cell used in taking the constant. For the present purpose let the tension be 100; then

(3.) Let the cable be tested for leakage in the ordinary way (287) by reading the deflection of the galvanometer, and let the deflection be 20 divisions.

(4.) Now the galvanometer with one cell through a resistance of one million ohms shows a deflection of 10 (1).

The tension of the battery is equal to 100 cells (2).

Therefore if 100 cells had been used in (1) instead of a single cell, the deflection would have been $10 \times 100 = 1{,}000$ divisions, and this would have represented a resistance of one million.

Lastly. The deflection through the cable is 20 divisions. Therefore 20 : 1,000 : : 1 million : 50 million ohms, the insulation resistance of one knot of the cable.

That is to say—multiply together the resistance and the value of the shunt used in taking the deflection from one cell, this deflection itself, and the number of cells; dividing the product by the deflection per knot: the result is the insulation resistance per knot.

It is obvious that any other resistance and any other shunt could be used in taking the constant. In cases where the shunts have not been arranged to reduce the sensitiveness of the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, or some other convenient multiple; or where, as is often the case, the resistance of the galvanometer or shunt is liable to change; these resistances must be determined, and the value of the shunt ascertained, by the formula given in the Appendix.

The greater the length of the cable the greater is the leakage; the observed resistance multiplied by the length in knots will therefore give the resistance per knot.

A perfect cable tests alike with either copper or zinc to earth, but a faulty cable tests worse with a negative than with a positive current (426).

451. *Insulation test by fall of charge.*—Insulation resistance can be determined from the loss of static charge, by means of the galvanometer or the electrometer. This test is comparative only, and will not give the resistance unless the electrostatic capacity of the core is known.

In testing with the galvanometer, charge the cable from a battery, discharge immediately, noting the deflection or swing of the needle. Charge again, leave the cable disconnected one minute, and again discharge; the difference gives the leakage in one minute.

The connections for a discharge test are shown in Fig. 109; when a condenser is used, one set of plates is connected in

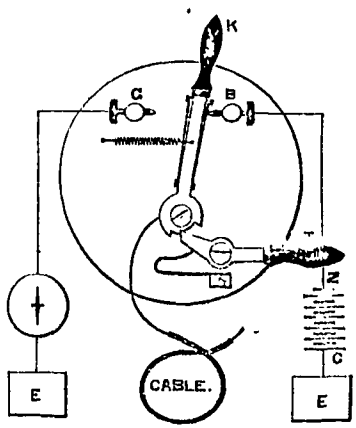


FIG. 109.

place of the cable, the other set to earth. The key is drawn in the position for charging; when it is released by lifting the trigger T, the cable is discharged to earth through a galvanometer. For a *charge* test, the galvanometer is placed between the cable and the key.

It requires a little practice to use an ordinary discharge key so as to obtain uniform results, and it is better to release it by a species of trigger, as shown in Fig. 109.

Or, instead of reading the discharge, read the charge by connecting the battery to galvanometer, and galvanometer to cable through the key, so that the charging current may pass through the galvanometer. Then after a minute, charge again, the cable having been left disconnected in the interval by placing the key K midway between the contact points G and B; the deflection will show the quantity which enters the cable to make up for that which had escaped during the minute. If insulation is perfect, charge and discharge will be equal. A somewhat heavy needle answers best for these experiments; if a Thomson with vanes of talc offering great resistance to the air is used, its readings will not be perfectly accurate (446), but corrections can be made to allow for the resistance of the air.

The loss may, as it were, be magnified by reading the charge in the first instance upon a shunted galvanometer and increasing its sensitiveness before recharging. For instance, the first charge may be read with a shunt of 1-10th, the last without any shunt; in which case the leakage will be multiplied by ten, or rendered ten times more apparent.

To test by the reflecting electrometer, connect the cable to the instrument and to the battery, note the deflection, then disconnect the battery and note the deflection after the minute. The fall of tension is beautifully shown by this apparatus, as the angle of deflection is always proportionate to the potential of the charge remaining in the cable.

452. *Fall to half-charge.*—The system of testing the insulation of cables by ascertaining the length of time required for the charge to fall one half, has so many advantages that it is likely to come into general use among electricians; it is independent of the length of the cable, and of the resistance and

electromotive force of the battery employed, nor is it necessary that the constants of the instruments should be ascertained, all which causes render it eminently suited for ascertaining the insulation of a submerged cable, and ascertaining its relative condition from year to year.

The ordinary method of testing by half-charge is to divide the testing battery into two equal parts, and to take an immediate discharge from the cable with each half in succession in the manner described in the next paragraph, taking the mean, which shows the deflection the cable will give when the charge from the *whole* battery has sunk to one-half. Charge the cable with the whole battery, and by a series of trials ascertain the time which elapses before the discharge sinks to that given by half the battery.

If an accurately graduated galvanometer be employed, it will not be necessary to halve the battery; an immediate discharge is in this case taken with the whole battery, and its amount divided by two for the half-charge.

The electrometer shows at a glance when the tension has fallen to one-half.

453. Clark has devised a simple method of making this test with any ordinary galvanometer, which is well suited for use on board ship or on the sea-shore.

Two condensers are employed, each having exactly the same electrostatic capacity. The cable is first charged from a battery for 10 or 15 minutes, to get rid of the effect of absorption. During this time one of the condensers is charged from the same battery, and then placed momentarily in connection with the second condenser, when the two will become charged exactly to half tension, the charge dividing equally between them (465). It only remains then to place them in connection with the cable through any galvanometer, at the time when it may be expected to have fallen to half tension; if this is done at the right moment, no charge will pass through the galvano-

meter in either direction; if the connection be made too soon or too late, a slight charge will pass from the cable into the condensers, or *vice versâ*, and the operation must be repeated. By a simple key, these connections are all made at pleasure by one motion of the finger, and in one or two trials the time of falling to half-charge is obtained with great precision.

The capacity of the condensers should not be large (about ·2 microfarad), so that if the test is made too soon it shall abstract but a very small portion of the charge. As the contact is of extremely short duration, there is no time for leakage to take place from the condensers, which would vitiate the result.

454. Before testing, put the cable to earth for several hours, to get rid of any charge which may accidentally have accumulated in it (see also 448). Use as low a battery power as possible, for energetic discharges are apt to demagnetize or reverse the needle; and when the ordinary insulation test and the discharge test are both used, the discharge must be taken first, because the high battery power used for the former will cause so much absorption as to increase the discharge.

455. *To calculate the time of fall to half tension by one observation.*—The time required for the charge to fall to one-half or any other fraction may be obtained from the fall observed during a given interval. This is very convenient when testing materials of high insulating powers which lose their charge very slowly. The charge leaks out very rapidly at first, the rate of falling decreasing as the tension lowers.

456. The following table, supplied by Mr. Latimer Clark, furnishes an instance of the rate of fall from tension to half tension in the Atlantic Cable of 1866.

ELECTROMETER TEST OF 1866 ATLANTIC CABLE, TAKEN SEPTEMBER 11TH, 1866—100 CELLS NEGATIVE.

Percentage of Charge remaining.	Observed Time of Falling.	Percentage of Charge remaining.	Observed Time of Falling.
	min. sec.		min. sec.
100	0 0	73	25 19
97	2 52	72	26 23
96	3 29	71	27 17
94	4 57	70	28 31
93	5 39	69	29 45
92	6 21	68	31 6
91	7 10	67	32 29
90	7 41	66	33 46
89	8 41	65	35 27
88	9 33	64	37 3
87	10 25	63	38 42
86	11 17	62	40 36
85	12 16	61	42 6
84	13 26	60	43 49
83	14 20	59	45 45
82	15 31	58	47 45
81	16 29	57	50 10
80	17 26	56	52 0
79	18 28	55	54 13
78	19 32	54	56 20
77	20 37	53	58 11
76	21 36	52	60 50
75	22 43	51	63 21
74	23 55	50	66 41

A rheostat, consisting of 100 coils, each of 1,000 ohms' resistance, connects the poles of a battery of 150 cells, the copper of which is put to earth. The tension in these coils will be greatest at the end connected to the zinc, falling regularly to zero at the opposite extremity. A wire is arranged to slide from end to end of the rheostat, so as to take up the tension of the point at which it may be placed. The cable is first charged by connecting it to the zinc of the battery; it is then removed and placed in contact with an electrometer; the wire is connected to the opposite side of the electrometer, and made to slide from point to point along the rheostat until it balances the declining tension of the cable, when its position on the slide shows the percentage of the charge remaining in the cable.

From this table it will be seen that whatever percentage of the charge escapes during the first minute, the same percentage of the charge, *then remaining in the cable*, will escape during the second minute, and so on; and the charges, if plotted out as ordinates and abscissæ, form a logarithmic curve.

457. The simplest way to show the mathematical law of the fall of charge from full to half tension is to consider it in reverse order, that is, to calculate the time it will take to *double* a charge accumulating at a regular known increment. This is simply an application of the principle of compound interest.

Thus, if C be the charge upon a cable, increasing by the compound ratio r, it is required to know the time that C will take to become $2\ C$. It is evident by the common rule of compound interest that at the end of the first unit of time, C will become $C + Cr = C(1 + r)$, in the second unit of time $= C(1 + r)^2$, and in n units of time $= C(1 + r)^n$.

But $$C(1 + r)^n = 2\ C,$$

therefore $$(1 + r)_n = 2,$$

which when r is known, will give us the units of time t that any cable will take to rise from half to full charge, and, *vice versâ*, *to fall from full to half charge.*

We find from Clark's table that in the case of the Atlantic Cable, r was 3 per cent. $= \frac{3}{100} = \cdot 03$, in the unit of time 2·87 minutes.

Therefore $$1 + r = 1{\cdot}03$$

and $$1{\cdot}03^n = 2$$

therefore $$n \log. 1{\cdot}03 = \log. 2.$$

$$n = \frac{\cdot 301}{\cdot 013} = 23{\cdot}15,^1$$

---

[1] ·301 is the log. of 2, and is therefore used in calculating the fall to half-charge. If any other fraction of the charge be required, the log. corresponding to that fraction is used instead of the log. of 2.

·013 is the approximate log. of 1·03.

which multiplied by the unit of time, 2·87 minutes, gives $23{\cdot}15 \times 2{\cdot}87 = 66{\cdot}44$, or 66 minutes 26 seconds.

Clark's observation gave the actual time as 66 min. 41 sec.

The formula is more simply given thus :—

$$nt = \frac{{\cdot}301}{\log.\,(1+r)}$$

where r = percentage of fall in n units of time t, t may be omitted if we make the unit of time one minute. The observation will not be so correct if a larger unit of time be taken.

Having, therefore, charged a cable to full tension, it is only necessary to allow it to leak one minute, and then, by comparing the difference of charge, to obtain the percentage of fall in the unit of time, and by means of the above formula to calculate the time it would take to fall to half-charge. (*Preece.*)

458. This law of compound interest is of very wide application in cable testing, not only as respects fall of charge, but also as regards the variation of resistance due to changes of temperature, both in metals and in insulators.

459. *The testing of joints.*—A joint should insulate as well, or nearly as well, as an equal length of the perfect core, and the object of the test is to ascertain if this be the case. Now the leakage, even from a considerable length of good core, is too small to affect the galvanometer; but although the electricity which escapes moment by moment cannot be measured, still if it were possible to store up the loss during a minute, and compel the accumulated loss to pass all at one moment through the coils, it would produce a sensible deflection.

In order to effect this, recourse is had to induction. A metallic trough, sufficiently large to contain two or three feet of the core, is suspended by straps or rods of polished ebonite, two or even three feet long. A small condenser is attached to increase its inductive capacity, and enable it to store up the electricity which may leak through the percha. The testing

battery, of not less than 200 cells, is insulated in a similar manner, and all loss over the surface of the conducting wires is prevented by paring their ends, so as to expose a fresh clean surface, or even by coating them with hot paraffin.[1]

To ascertain if the apparatus is sufficiently insulated, the trough and condenser are charged, and the swing of the needle, from an immediate discharge, noted. They are then recharged and left free for a time equal to that to be occupied by the test, and again discharged. The difference in the swing shows the loss in the time, and should be very small.

The joint is placed in the trough, a negative current is applied to the cable, and the positive pole of the battery is connected to the outside coating of the condenser. Any leakage which may occur through the percha is by this arrangement accumulated in the condenser, and may be discharged through the galvanometer after any given interval.

An equal length of the core without a joint is now substituted and tested in the same manner, and thus the insulation of the two are compared.

It is possible to find how much is lost by defective insulation during the joint test itself; but as both core and joint are subjected to the same conditions, and the object is simply to see if one insulates as well as the other, this precaution does not seem to be absolutely necessary.

To make the test. 1st. Place the joint in the trough—leave one end of the cable free; connect the copper pole of the battery to the galvanometer; connect the other terminal of the galvanometer to the trough, and, finally, charge the cable by applying the zinc pole.

The charge within the cable acts inductively upon the natural electricity of the trough, the wire being in fact the inner,

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[1] Paraffin oil may be used in an emergency, but never except where the part coated can be cut away, as the oil has a softening effect on percha.

and the water the outer coating of a Leyden jar. A portion of the negative electricity of the water is set free, and an equal quantity of the positive is held fast or disguised by the negative charge within the cable. The free electricity is at once neutralized by the action of the battery; if it were not so arranged, it would increase the apparent leakage from the cable, being of a similar sign.

The deflection or swing due to the discharge being instantaneous, it follows that if the needle *remains* deflected after the discharge, the joint is very bad, or there is leakage over the surface of the percha. The latter may be conducted to earth so as not to interfere with the test, by wrapping an earth wire round the core a few feet from the free end.

2nd. Without disturbing the charge of either cable or trough, connect one coating of the condenser to the trough, the other coating to the + pole of the battery, the zinc being to the cable as before.

Any negative electricity which may leak from the cable will now accumulate in the condenser. Allow one minute for this.

3rd. Disconnect the condenser from the trough and battery, and discharge it through the galvanometer. If the trough and other parts of the apparatus have been well insulated, the swing will show the accumulated leakage from the portion of core under test. It is evident that these changes must be made by perfectly insulated keys and commutators.

This method somewhat differs from that ordinarily adopted. It is usual to put one pole of the battery to earth; but in this case leakage takes place over the whole cable, however long it may be. By the plan described, the leakage is confined to the part in the trough, and the whole force of the battery is concentrated there, and the apparent leakage exaggerated.

460. *Joint testing by electrometer.*—In joint testing, an electrometer is frequently used instead of a galvanometer for ascertaining the amount of "accumulation." Its great advantage over

the galvanometer is the absolute knowledge it gives of what is passing throughout the entire duration of the test. With the galvanometer it is impossible to know anything of what may have happened during the test, or its probable result, until the time for taking the discharge has arrived. The electrometer

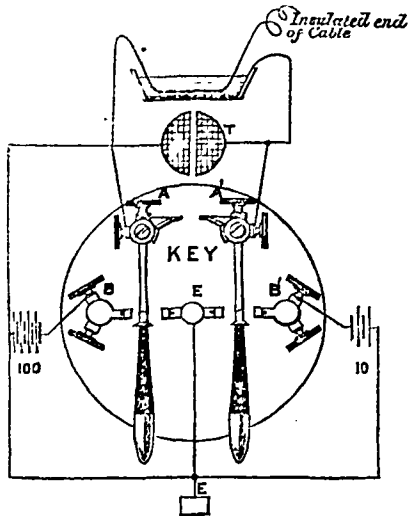

FIG. 110.

shows one what is taking place from the commencement, the gradual accumulation is observed, and any fault or accidental touching of wires is at once noticed.

The connections are similar to those for the galvanometer, and the alteration is simply in the observing instrument.

The use of an ordinary condenser has been abandoned; for in practice it is found that where the accumulation from a joint is very small, the condenser is liable to give fallacious results. It frequently accumulates of itself, and if it has been used for any other tests, it is most difficult to clear it of its charge, all condensers being made of material that retains its charge most obstinately. The testing room being generally at some little distance from the factory, it is found in practice that the *lead* to

the trough possesses sufficient capacity to be employed as the condenser. When a lead is thus used it is essential that its insulation should be perfect, and it is advisable to have it placed along the ground so as to increase its capacity, and at the same time to remove it to a distance from the charging wire, for when leads are near one another there is sure to be induction between them.

Fig. 110 shows the arrangements for this form of the test. A A′ are levers mounted on ebonite pillars and furnished with long ebonite handles tipped with bone or ivory. These levers are pivoted so that they can be brought into contact either with B, or E and B′, or E, respectively. B and B′ are terminals insulated in the same manner as the levers A A′, while E is a plate mounted on a *brass* pillar. These five pillars are screwed into a brass foot-plate connected to earth. The ivory tips to the lever handles are intended to prevent the excitation of electricity which would occur if the hand was allowed to slide along the ebonite in the act of moving the levers, no such effect being produced by rubbing the ivory.

Brass is used for the foot-plate to prevent surface conduction between the several levers and terminals, by conveying all leakage to earth. The electrometer is Thomson's reflector.

The joint in the trough is connected to the terminal A, its other end being insulated. The trough is connected to one half of the electrometer and to the key A′; the other half of the electrometer is connected to the earth. The terminal B is joined to a battery of 100 cells or more, the opposite terminal B′ to a battery of 10 cells. When at rest the lever A′ is pressed to the left, keeping the electrometer in short circuit through the earth connections.

In testing a joint for leakage, the insulation of the trough is made sure of by pressing the lever A′ to B′, charging the trough and electrometer to the potential of the 10 cells; as soon as the spot of light on the scale is steady, the lever A′ is freed,

when the deflection will fall gradually in proportion to the leakage of the trough; if the fall be rapid, the trough and all connections should be cleaned; if, however, the fall be slow (there must be always some loss, this depends more upon the state of weather than anything else) the joint may be tested.

Short-circuit the electrometer to discharge it, and when at zero open the circuit, pressing at the same time the arm A to B so as to charge the cable and joint with the 100 cells; the inductive discharge of the trough will be then seen, and should be noted. Again, short-circuit the electrometer, and when the spot is steady at zero, open the circuit and watch the electrometer during the time fixed for the accumulation; say one minute, or two minutes. It will be seen that the potential of the lead and trough, which was at first nil, is now slowly increasing, and is of the same sign as the charging current. The potential at the end of the fixed time is the amount of accumulated loss through the joint during that interval. This should be subsequently compared with the loss from an equal length of core tested in the same manner.

After the accumulation has been observed, short-circuit the electrometer, and observe the inductive discharge on breaking battery circuit at B.

It often occurs, when there are several wires in the cable, that the apparent leakage is greater from the joint which is first tested, than from any of the other joints tested at the same time. This arises from the charge in the first wire acting upon the others inductively. The wires not under test should therefore be put to earth until they are wanted, and the condenser and trough should be perfectly discharged between each test.

It will be understood that the results are simply comparative, not absolute; all that the method effects is to show the difference between the insulation of a joint and that of any other part of the core.

Inductive, or Electrostatic Capacity.

461. The speed of a cable is proportional to its *inductive* or *electrostatic* capacity, which is measured by the charge it is capable of receiving. By the *capacity* of a condenser or cable is meant its power to receive a charge; the *specific* capacity of a cable is this power when considered with reference to an unit of length: thus if in two cables, each one knot long, the one is able to take double the charge of the other, its specific capacity will be double. The specific inductive capacity of an insulator is defined by par. 142. For percha it is 4·2, for Hooper's material 3·1, and for pure rubber 2·8,—air being 1.

Inductive capacity is increased in a very small degree by increased pressure or elevation of temperature.

462. *Formula for capacity.*—Thomson has calculated the following formula for the specific inductive capacity of a cable from the known laws of induction between concentric curved surfaces; and its truth has been confirmed by experiment:—

The specific inductive capacity of the material used as an insulator, divided by twice the Napierian[1] logarithm, or $\log._{\epsilon}$, of the ratio of the diameters of the coating and conductor; a deduction of five per cent. being made from the diameter of *strand*. Thus—let D be the outer diameter of the core, d the diameter of the conducting wire, and I the *specific* inductive capacity of the insulator.

The specific inductive capacity of the cable $= \dfrac{I}{2 \log._{\epsilon} \dfrac{D}{d}}$.

463. If a thickness of coating t produces a certain inductive capacity, to halve this capacity another layer must be added

[1] Thomson uses the Napierian log. or $\log._{\epsilon}$, for mathematical reasons, but the ordinary log. is most generally used in cable tests. To convert an ordinary log. into $\log._{\epsilon}$, multiply by 2·303.

which is as much greater than t as the diameter D of the coating is greater than that of the conductor d; that is,

If a thickness t give a capacity of . . . . . 3·0

A thickness $t + t\frac{D}{d}$ will reduce the capacity to . . 1·5

And „ $t + t\frac{D}{d} + t\frac{D^2}{d^2}$ „ „ to . . 1·0

When the diameters of the conductor and insulator preserve the same ratio one to the other, the inductive capacity remains constant.

464. *Unit of capacity.*—The unit used in cable tests is a microfarad, or the millionth of a *farad,* and is a condenser which contains, when one side is put to earth, that quantity of electricity which, with an electromotive force of one *volt* (about one Daniell cell) would flow through a resistance of one megohm in one second.

The Committee of the British Association has not at present issued authorized copies of the standard; but condensers whose approximate value in farads has been determined may be obtained. They are generally made of sheets of tinfoil separated by mica, or paper soaked in paraffin, but sometimes a knot of cable is used. The capacity of the Atlantic Cable is 0·3535 microfarad per knot.

Each coil of core is tested to ascertain if its capacity agree with the standard determined on, and if it prove too high, the capacity of the insulating material is too great or its thickness too small.

465. *Distribution of charge,* when two cables or condensers are connected together.—If a charged cable or condenser be joined to one not charged, the charge will divide itself between the two in proportion to their respective capacities, the tension becoming the same in both.

Let C be a standard condenser charged to tension T, and let

x be another condenser or cable, and t their joint tension when combined.

Then $$t : T : : C : C + x,$$

and $$C\,T = C\,t + x\,t.$$

The capacity of x will be—

$$x = \frac{T - t}{t}\,C.$$

In a number of cables connected together at their charging ends, with their distant ends insulated, the charge is equal to what would have been obtained had they been joined in one continuous length.

466. *Measurement of charge.*—As has already been stated, a cable is charged by connecting one pole of a battery to earth or the outer sheath, and making contact between the other pole and the cable by means of a key. If a galvanometer is placed in the circuit, so that the charge may pass through it, the needle receives a sudden impulse, as if given by a blow, and therefore the forces acting upon it are proportional to the *sines of half the angles* described, which, for angles not exceeding 30°, are nearly proportional to the angles themselves. Thus, if the Thomson reflecting galvanometer, whose angle of deflection is very small, is used, the forces are proportional to the scale readings themselves.

This is only true, however, when the duration of the current is very short as compared with the time the needle requires to complete its swing, for if its duration is sensible it is rather a push than a blow. The needle should swing slowly; it should be heavy, and be suspended very freely, without any resistance from the air. Large mirrors or large talc vanes are therefore improper, because they check the swing.

Jenkin gives the following correction for the resistance of the air when it is but slight. Observe the extent of the first swing to one side of zero—say the right; allow the needle to continue to oscillate, and note the extent of the second swing to the same

side of zero, which will be less than the first. Now, as this diminution is entirely due to the resistance of the air, and as it has been effected during the swing of the needle from right to left and back again, the needle would have swung further at first by one-fourth of this amount had no air been present, because during the first swing from zero to the right the needle passed over only a quarter of the space travelled afterwards. One-fourth of the difference between the first and second deflection should therefore be added to the reading. In cables more than 150 miles in length the currents have a sensible duration, and this method of measurement does not apply with accuracy.

When insulation is perfect, charge and discharge are equal; when faulty, discharge is less than charge by the amount of leakage. An instantaneous discharge is not affected by slight leakage, for the charge has not *time* to escape.

In perfectly similar cables, insulated at their distant ends, charge is in direct proportion to their lengths, and to the number of cells used.

In cables of similar length and of similar materials, but of different dimensions, charge is inversely proportional to the log. $\frac{D}{d}$. The larger the logarithm, the smaller the capacity of the cable.

467. *Method of showing induction in short lengths.* — The effects of induction may be shown upon very short lengths of cable, by the use of an instrument called by the Germans a *wippe* or *whip*, which is a rocking lever connected to the cable, carrying a spring caused to vibrate very rapidly between two stops, connected, one to a powerful battery, one pole of which is put to earth, the other to a galvanometer, also on earth. The cable is thus charged and discharged through the galvanometer so rapidly that the several impulses aid one another, and increase the deflection.

In this case the charge, instead of being represented by a

sudden impulse, is indicated by a constant deflection, and is therefore proportional to the sine of the angle described by the needle, instead of half its sine. Siemens gives the following formula for the value of these deflections.

If a is the sine of the angle through which the sine galvanometer must be turned to bring the needle to zero, n the number of charges or discharges per second, e the electromotive force of the battery, we have

$$\text{Capacity} = \frac{a}{e}\, n;$$

and if the velocity of the apparatus remain the same, the capacities of two cables, or of a cable and a condenser, are directly proportional to the sines of the deflections obtained from each.

By placing an insulated spring upon the opposite end of the lever, so as to vibrate between a second pair of contacts, the apparatus can be made differential.

468. Methods of Testing for Capacity.—This test is taken with a small number of cells, seldom exceeding ten, and will, in consequence, be affected by electrification or a charge remaining in the cable after a previous test. It is therefore always taken before the insulation test, which requires 200 cells or more.

(1.) When the capacity of the condenser and cable are nearly equal, the charge or discharge of each can be read directly from the galvanometer, and will be proportional to the swing of the needle, corrected by the method given in par. 466.

Let C be the capacity of the standard condenser in farads; D the deflection or swing of the needle from its charge or discharge; c the capacity of the condenser or cable to be measured; and d the swing from its charge or discharge. Then

$$D : d :: C : c.$$

(2.) When the capacities are unequal, so that their charge cannot be read off from the same scale, and c is greater than C.

Take a reading from C; then from c. Shunt the galvanometer by resistance coils until the deflection obtained from c is the same as that previously obtained from C, then

$$c = \frac{g + s}{s} C.$$

Where g is the resistance of the galvanometer, and s that of the shunt.[1]

When C is greater than c the process is reversed, the galvanometer being shunted in taking the reading from C, and

$$C = \frac{g + s}{s} c.$$

The greater the swing, the less the effect of a small error of observation. In using a reflecting galvanometer, the deflection may be taken across the whole length of the scale, instead of from its centre. To eliminate error resulting from the unknown resistance of the wires which connect the rheostat used for the shunt, a known resistance may be added to the galvanometer, so as to permit the use of a shunt so large that the resistance of the connecting wires may be neglected.

As the resistance of copper wire is considerably affected by alterations of temperature, it is convenient to use a galvanometer of German silver wire, which is far more constant, for capacity or insulation tests.

469. In testing with a differential galvanometer, one coil is connected to the standard, the other to the cable. The latter is shunted until the effect of the charge in each coil is alike, and the needle remains unmoved; when the capacity of the condenser, multiplied by $\frac{g + s}{s}$, where g is the resistance of *one* coil of the galvanometer, gives the capacity of the cable. If the cable is less in capacity than the condenser, the coil to which the latter is connected must be shunted.

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[1] See article on shunts in the Appendix.

The formula may be generally expressed thus :—

Let s = the resistance of the shunt.
g = that of one coil of the galvanometer.
c = the lesser charge or discharge.
C = the greater charge or discharge.
Then $s : s + g :: c : C$.

As charge is directly proportional to the tension of the battery, the number of cells may be varied, until equal deflections are obtained both upon the condenser and the cable; when their capacities will be directly as the number of cells used for each test. Care must of course be taken to choose cells which are precisely equal, or to ascertain their relative tensions.

470. *To find the capacity without the aid of a condenser.*—Shunt the reflecting galvanometer, and add resistance until a readable deflection is obtained with the battery with which the cable is to be charged. From these data calculate what total resistance R (including that of the galvanometer and battery) would be necessary to reduce the deflection to one degree, which is the unit deflection.

Next, count the number of oscillations which the needle makes per minute when swinging freely, not under the influence of a current. Let t be the time of half a complete oscillation.

Lastly, let d be the deflection produced by an immediate discharge; then

$$\text{Capacity} = 2\,\frac{t\ sin : \frac{1}{2}d}{3{\cdot}1416\ R}. \qquad (Jenkin.)$$

471. *To obtain the tension of a whole battery in terms of that of one or more cells.*—It is necessary in all cases in which comparative tests are made with varying battery power, to know exactly the relative tension of the cells used; for this is not always proportional to their number.

Charge a *condenser* by a single cell, discharge it through a reflecting galvanometer or other sufficiently delicate instrument, noting the deflection obtained. Charge the condenser by the whole battery, and *shunt* the galvanometer until the deflection is the same as that given by the single cell. Then, the number of times the tension of the battery exceeds that of the cell first tested is given by the formula $\frac{g}{s} + 1$, where g is the resistance of the galvanometer, and s that of the shunt.

For example, it is required to know the value of a battery of 200 cells used to test a cable, in terms of the single cell used to take the *constant* (449) of the galvanometer.

Let $g = 5{,}400$ ohms and $s = 30$ ohms, then $\frac{g}{s} + 1 = 181$;

that is to say, the 200 cells are equal only to 181 such cells as the single one with which the constant was taken.

Or take a discharge d from the single cell; then, after shunting the galvanometer to $\frac{1}{10}$ or $\frac{1}{100}$, according to the number of cells to be tested, take a second discharge D.

Then $\frac{D\,s}{d}$ = the tension of the entire battery.

For example, if the discharge from the single cell gives a deflection of 120 divisions, and the battery of 200 cells 180 divisions with the $\frac{1}{100}$ shunt, then

$$\frac{180 \times 100}{120} = 150 \text{ the value of the 200 cells.}$$

472. *To calculate the insulation resistance from the time of falling to half charge.*—This may be calculated by the following formula:—

$$\text{Resistance} = \frac{t}{f \log_{\epsilon} \frac{C}{c}}$$

Where f is the capacity of the cable, in microfarads;

C the observed tension, as shown by the deflection on charging;

c the tension after a certain time; and

t the time occupied in falling from C to c, which should be one minute.

Common logarithms may be used instead of the hyperbolic system, or log. ϵ, by employing the constant or multiplier 2·3; thus the formula may be

$$\text{Insulation resistance } R = -\frac{t}{2{\cdot}3 \times \log.\frac{C}{c} \times f}.$$

When f is in microfarads per knot, the insulator R is in megohms.

The converse of the formula will give capacity

$$f = \frac{t}{2{\cdot}3 \times \log.\frac{C}{c} \times R}.$$

473. *To calculate the specific resistance of the material with which a cable is insulated.*—This may be determined from the observed resistance of a known length.

Find the resistance of the insulator from a mean of many observations at the same temperature upon a known length of cable l; let r be the observed resistance, D the diameter of the core, d the diameter of the conductor; then—

$$\text{The specific resistance} = 2\,\frac{3{\cdot}1416\,l\,r}{\log.\frac{D}{d}}.$$

474. *To calculate the leakage of a cable from the known leakage of an equal length of another cable, composed of similar materials, but in different proportions.*— Let D and d be the diameters of the core and conductor whose leakage a has been *ascertained*, and D' and d' the corresponding dimensions of the cable whose leakage a' is *required*. Then—

$$a' : a :: \log.\frac{D}{d} : \log.\frac{D'}{d'}.$$

When the two differ in length, calculate as for equal lengths and reduce by proportion, leakage increasing directly as the length.

475. *To find the weight and thickness of insulating material* required to produce a core equal in inductive capacity to a given cable whose conductor is similar, but which is insulated with a different material.

Let the diameter of a percha core be ·348 in., the diameter of the conductor ·102 in.; it is required to find what thickness and weight of Hooper's material is required to produce a core of equal capacity, using a conductor of the same diameter.

(1.) To find the diameter. The specific inductive capacity of percha is 4·2, and that of Hooper's material 3·1, air being 1 (461); and the logarithms of the ratio $\frac{D}{d}$ in cables of equal capacity, where the conductor is similar in both, will necessarily be in the proportion of the specific capacities of the insulating substances.

Then to find x, the required diameter of the core, say

$$4{\cdot}2 : 3{\cdot}1 : : \log. \frac{{\cdot}348}{{\cdot}102} : \log. \frac{x}{{\cdot}102}$$

by which x is found = ·253 nearly.

(2.) To find the weight per knot. The specific gravity of the two materials are as 5 to 6, percha being the lighter of the two. By Clark's formula (Appendix) the weight of percha per nautical mile is $\frac{D-d^2}{481}$ lbs. which for the present cable is $\frac{253^2 - 102^2}{481} = 111$ lbs. Then 5 : 6 : : 111 : 133. The diameter of the required core is therefore ·253 in.: and the weight per knot, 133 lbs.

476. *Precautions in testing.*—As the leakage from a good cable is extremely small, it follows that unless the batteries, keys, and other apparatus used to test it are perfectly insulated, the loss through them may be almost as great as that of several

miles of core. The leakage over the surface of the percha must also be prevented by carefully paring the ends of the core, and even washing them with paraffin oil or coating them with solid paraffin, when very accurate tests are required.

The keys must be mounted on ebonite, and the batteries placed on ebonite supports, or slung by percha straps.

The wires leading from the batteries or cable tanks to the testing room must be *perfect* as to insulation, or their loss or leakage ascertained before each set of tests, with the minutest care. They must not be so near as to influence one another inductively.

The support for the galvanometer should be of massive brick or stone, placed east and west on a sound foundation, so as to prevent vibration; and because of the disturbing effect on a magnet of masses of iron in motion, the testing room should be as far from the factory as possible, or tests can be made only when the machinery is at rest.

When the galvanometer is adjusted for excessive sensibility by lessening the directive force of the needle, the zero point is liable to alteration from the twisting of the suspending fibre. It is therefore better to use a higher battery power and a less sensitive needle.

The Leclanché battery is very suitable for insulation tests, but the Daniell or one of its modifications must be employed for measuring low resistances, such as that of the copper conductor. Great care must be taken to prevent powerful currents passing through the galvanometer, as they may seriously interfere with its magnetism and its adjustment. In testing for insulation, the galvanometer is short-circuited to prevent the inductive charge passing through it. The short circuit can be broken at the half minute, and the deflection read at the end of the minute.

477. In using the balance for the resistance of the copper conductor, the ratio between the arms A and C may conveniently be 10 to 100 ohms when the cable is under 4 or 5 miles; it may

then be made 100 to 1,000 ohms; the resistance can then be read correctly within one-tenth of an ohm.

The galvanometer is shunted to reduce it to the needed amount of sensibility, and low battery power is employed.

When the resistance is unknown, the current passing through the galvanometer may be powerful; in all tests, therefore, the galvanometer key should not be firmly depressed, but tapped lightly and quickly, so as to allow a very slight current to reach the coil; its *direction* can then be ascertained; whereas if the key were held down, the spot of light would be driven across the scale suddenly, and would continue to vibrate to either side, so that its direction would be unknown, and much time would be lost in waiting its return to zero.

If adding or decreasing resistance in the balance do not alter the direction of the deflection, the connections will have been incorrectly made.

When the connections are properly adjusted, it will be seen that when the resistance of the measuring coils is too great, the deflection is to one and the same side of zero, and to the opposite side when too small; let then the arrangement of the wires be noted, so that the direction of deflection may in all cases indicate at once whether the coils have too much or too little resistance; this will save much time and trouble.

After the direction of the deflection has been brought under command, alter the measuring coils until the light is brought near zero, then increase the sensitiveness of the galvanometer by lengthening its shunt, and complete the measurement. In these final tests the key may be firmly pressed, but in all cases it must be released when the resistance is about to be altered, as the alteration may cause too large a movement of the light. This is especially necessary when resistance coils are used, in which the shifting a plug breaks the circuit.

The plugs must be kept scrupulously clean, and the contacts firmly made.

Methods adopted in testing the French Atlantic Cable of 1869.

478. (A.) Tests applied to the Core.—The core, after it has been manufactured about fifteen days, is immersed in water, at a temperature of 75° Fahr., for twenty-four hours, when careful observations are made on each coil.

Obs. 1. The *resistance* of the conductor is determined. In the cable in question this was about 3·25 ohms for each coil, and was compared with a standard of 3·25 ohms, also immersed in water to secure uniformity of temperature. In diagram 1, $e\,f$ is a platinum-iridium wire stretched parallel to a metre scale divided into millimetres. The ends of this wire are soldered to massive copper bars to which the resistance coils R and R' are connected. These coils have each a resistance equal to that of 2·333 metres of the platinum-iridium wire.

The testing battery is one zinc-platinum cell; the galvanometer resistance is ·5 ohm only; the key is so arranged as to close the battery circuit first, then that containing the galvanometer; r' is the standard of 3·25 ohms; r the coil of core under test; and m a contact piece, sliding upon the stretched wire $c\,f$. The commutator is so arranged that either R and r', R' and r can be connected (as shown by the diagram), or, reversing the connections, R and r, R' and r'. To observe, press the key and slide m along cf until no current passes through the galvanometer, then reverse the commutator and take another reading. The connections should be made by mercury cups.

Let the reading $e\,m = x$ in the first observation, when R and r', R' and r are connected; and x' in the second, when the connections have been reversed.

Then the resistance of the core $r = r' \dfrac{2{\cdot}833 + (x' - x)\frac{1}{2}}{2{\cdot}833 - (x' - x)\frac{1}{2}}$,
where x and x' are expressed in millimetres . . . . . (1).
$(x + x')\frac{1}{2}$ should equal 500 ohms nearly.

Obs. 2. The *insulation-resistance* of the percha after one minute's electrification is determined both with negative and with positive currents from a battery of 100 cells, allowing a sufficient time between the two observations for the core to discharge itself perfectly. The current is passed through the galvanometer into the conductor, the opposite end of which is free, and the deflection is read after one minute. The galvanometer is, in the first instance, short-circuited so as to prevent the charge passing through it. If d is the deflection and c the constant of the galvanometer, the insulation-resistance $= \dfrac{c}{d}$ . . . (2).

Obs. 3. The *constant C* is found in this way. (Diagram 3.) A condenser is charged with one cell and discharged through the galvanometer (g) with shunt s', giving a deflection d'.

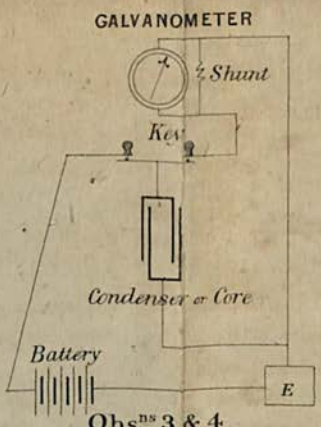
The condenser is next charged with 100 cells and discharged through the galvanometer with shunt s'', giving a deflection d''.

The current from one cell is passed through 10,000 ohms' resistance, and then through the galvanometer shunted with s''' giving the deflection d'''.

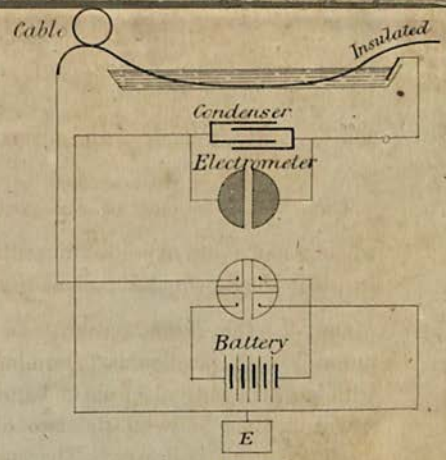
Then $$C = d''' \frac{d''}{d'} \times \frac{g \times s''}{s''} \times \frac{s'}{g + s'} \times \frac{g + s'''}{s'''}$$
$$\times (10{\cdot}000 + \textit{resistance of cell}) \quad . \quad . \quad . \quad (3).$$

Obs. 4. The *rate* at which the core *loses a charge* when the ends are insulated is determined in the following way:—

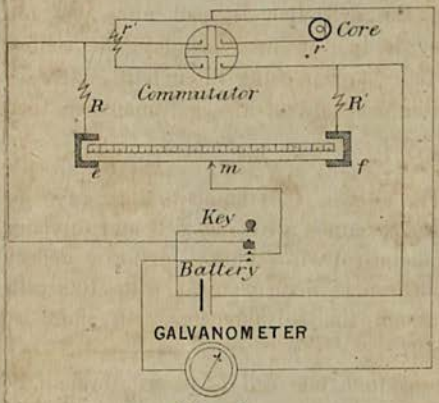
The coil is charged for 15″, then insulated, and after having been insulated 60″ is discharged through the galvanometer, giving a deflection d'.



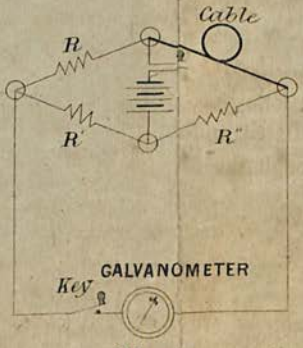
Obs^{ns} 3 & 4



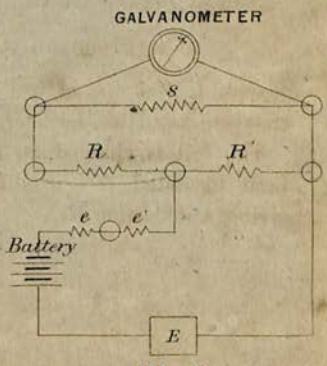
Obs. 6.



Obs. 1.



Obs. 8.



Obs. 9.

It is then recharged and immediately discharged, giving a deflection d.

The loss per cent. $= 100 \frac{d - d'}{d}$ . . . . . (4),

and the effective mean insulation during the time the coil remains insulated being R,

$$R = \frac{60}{2{\cdot}303 \times \textit{capacity} \times \textit{log.} \frac{d}{d'}} \quad . \quad . \quad . \quad (5).$$

R is in megohms when capacity is in microfarads.

OBS. 5. The capacity of each coil is determined thus:—

A condenser of a capacity of 0·355 microfarad is charged, and discharged through a galvanometer with a shunt s', as in Obs. 3, giving a deflection d'. Then a coil which, in Obs. 4, gives the deflection d with the shunt s, has a

$$\textit{Capacity} = d \frac{g+s}{s} \times \left(\frac{s'}{g+s'} \times \frac{1}{d'}\right) 0{\cdot}355 = a\,d \quad . \quad . \quad (6).$$

s is generally alike for all the coils, so that

$$\frac{g+s}{s} \times \frac{s'}{g+s'} \times \frac{1}{d'} \times 0{\cdot}355$$

is first found. Calling this expression a, the capacity of any coil is $d\,a$.

The same battery is used for 4 and 5. It consists generally of 50 cells.

(B.) TESTS APPLIED TO THE CABLE.—The several coils of core are jointed together, placed in cold water, and tested before they are served.

OBS. 6. *Tests of joints* (diagram 6).—The joint is placed in an insulated trough partly filled with water, one end of the conducting wire is connected to a key, the other is left free. A metal plate placed in the water is connected by an insulated wire with one side of a condenser having a capacity of 0·05 microfarad,

and also with one electrode of a reflecting electrometer. The other electrode of the electrometer is connected to the remaining side of the condenser and with the earth.

The observation is made thus. The two electrodes are connected together, and the battery is put on the coil. The electrodes are now separated and the battery is *reversed*, and the deflection caused by the inductive charge consequent upon the reversal of the battery is observed; to see that the connections in the factory are in order, and that there is the usual length of core in the trough.

The electrodes of the electrometer are again connected together until 15″ have elapsed since the reversal of the battery; they are then separated, and after an interval of 60″ the deflection (d) of the electrometer is observed.

The joint is then removed, and a standard consisting of six feet of the core is placed in the trough in its place, tested in a similar way, and the deflection obtained compared with that from the joint.

Now, if the electrometer be so adjusted that each division of its scale corresponds with a difference of potential of $\frac{1}{n}$th of the battery power used, and if the capacity of the condenser and connecting wires be c microfarads, the insulation resistance of the joint, in megohms, will be very nearly equal to $\frac{60}{cd}$ . . (7); and if the length of the core placed in the trough, and that of the joint itself, are known, the insulation of the joint can be compared with that of an equal length of perfect core at 75° Fahr.

Obs. 7. The *insulation-resistance* of the served core is determined by method 2, the zinc pole being put to the cable and the copper to earth; and is reduced to 75° Fahr. by the formula

$$Log. \frac{Resistance\ at\ temperature\ t}{Resistance\ at\ temperature\ t'} = (t' - t)\ \cdot 0506 \ . \ . \ . \ . \quad (8).$$

It is then compared with the former tests.

The temperature is carefully taken by a thermometer which has been compared with a standard.

Obs. 8. The completed cable is tested daily for the *resistance of the copper conductor;* 10 cells being used and the electric balance. (Diagram 8.)

R is a resistance that may be varied from 0 to 10,000 ohms. R' and R'' resistances of 10 and 100, or of 1,000 and 10,000 ohms. The battery is first connected, shortly after, the galvanometer, and the resistance R is altered until no current flows through the galvanometer. When this is the case, the resistance of the conductor of the cable $= R\frac{R''}{R'}$ . . (9), from which the resistance of the connecting wires must be deducted.

The resistance so found divided by the length of cable in circuit, gives the resistance per unit of length; which is compared with previous determinations under Obs. 1, after having been reduced to 75° Fahr. by the following formula:—

Resistance at t degrees = resistance at t′ degrees

$$\left(1 + (t - t')\ 0{\cdot}00402\right) \quad . \quad . \quad . \quad (10).$$

Obs. 9. The insulation-resistance is also determined daily as in experiment 2; as a rule, opposite currents are used on alternate days. The constant is, however, usually taken by direct deflection, in the manner shown by diagram 9, in which s is a shunt, R, R', e and e', resistances. The current passes through e and e', and then splits between R' and R, together with g and s; call the deflection of g, d. After reading d, e is removed, and the shunt s diminished until the deflection becomes the same as before. Let the diminished shunt be s'. Then the

$$\text{constant} = \left(\frac{(R + R' + g'') \times (R + R' + g')}{R'\,(g'' - g')} \times e + R'\right) \times \frac{d}{R + R'}$$

where $g'' = \frac{sg}{s+g}$ and $g' = \frac{s'g}{s'+g}$ . . . (11).

OBS. 10. The inductive capacity is determined as in experiment 5. The cable is charged with 10 cells, and discharged through the galvanometer with properly arranged shunts; the discharges are compared with those obtained with the same battery from a condenser of 0·1 microfarad (see equation 6).

OBS. 11. The rate of loss of charge is determined thus (diagram 11). One end of the cable is insulated, the other is connected to one electrode of a reflecting electrometer; the opposite electrode is attached to a switch by which it can be joined to either pole of a battery of 50 or 100 cells, or to earth direct. The electrodes are first connected together and put to earth, then separated without altering the earth connection; the electrometer being watched, and the process repeated, until the cable is found to be perfectly discharged.

Secondly, the electrodes are again connected together, and the cable is charged for 20″, and the deflection read after 60″. *The loss of charge per cent.* is then equal to $\frac{deflection}{constant} \times 100$, where the constant is the ratio of the whole battery power to the electromotive force, indicated by a deflection of one division on the electrometer scale.

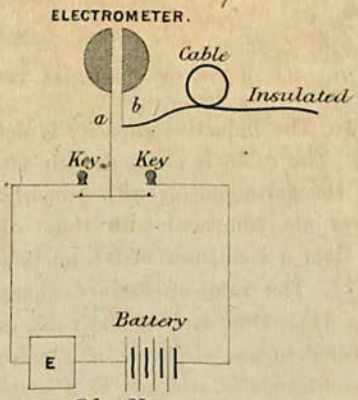
OBS. 12. This *constant* is found thus (diagram 12). The current passes through a small resistance s, and then through a large resistance R to earth; the electrometer being connected as in the diagram, the deflection (d) is observed.

s is then reduced to $\frac{s}{2}$ and R to $\frac{R}{2}$ and the deflection (d') read, when the

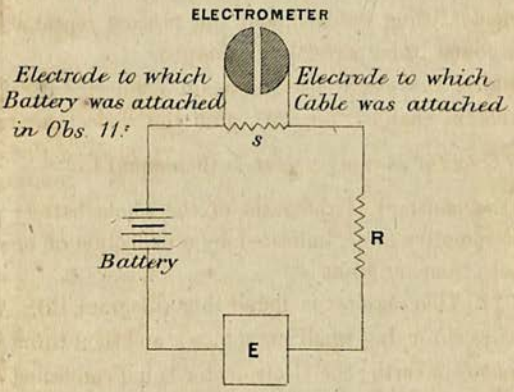
$$constant = d\,\frac{R+s}{s}\left(1+\frac{d-d'}{2\,d'-d}\right) \quad . \quad . \quad . \quad (12).$$

The arrangements should be such that $d - d'$ is small.

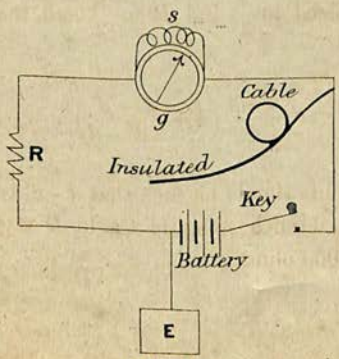
In testing the French Atlantic Cable, R was usually about 57,000, and s 10,000 ohms.



Obs. 11.



Obs. 12.



Obs. 15

The constant being found, the loss per cent. is $100 \frac{d}{constant}$ and the insulation per knot

$$= \frac{60}{2{\cdot}303 \times cap.\ per\ knot \times \left(2 - g\left(100 - \frac{100\,d}{constant}\right)\right)} \quad . \quad . \quad (13).$$

which is the same expression as in equation (5).

C. TESTS ON BOARD SHIP.—After the cable is shipped, the copper resistance is taken by method 8, and the *temperature* is calculated thus.

OBS. 13. Let R be the resistance of one knot of *pure* copper wires of the same diameter and weight as the core at 75° Fahr.

Let R' be the resistance per knot as originally found by Obs. 1, in the tank heated to 75°.

And let R'' be the resistance per knot as observed on board ship.

Then the temperature of the copper

$$= \frac{R' - R''}{R'' - R' + R} \times \frac{1000^\circ}{4{\cdot}02} \text{ Centigrade.}$$

The temperature, as thus found, is compared with that of the water in the cable tank as determined by a thermometer.

OBS. 14. *The insulation-resistance*, which has now very much lessened, owing to the increased length of cable under test, is taken by direct deflection, the effect of electrification being observed by keeping the battery current on for 20 or even 30 minutes, taking readings every minute.

The cable is then put to earth, and when discharged, a similar series of readings is taken with the battery reversed. If the cable is perfect, the whole set of readings should be identical with either current.

OBS. 15. *Capacity.*—On board ship with a long cable in circuit a different method from that adopted in Obs. 5 is necessary. The cable is connected as shown by diagram 15; the resistance R being large, yet greatly smaller than the insula-

tion-resistance of the whole cable. It should be such that the cable shall lose half its charge in 60 seconds.

The battery key is closed, and after the current has been applied about ten minutes, the deflection (d) is read.

The battery key is then opened, and 60 seconds after, the deflection (d') is observed.

The capacity of the

$$cable = \frac{60}{\frac{R'\left(R+\frac{s\,g}{s+g}\right)}{R+R'+\frac{s\,g}{s+g}} 2{\cdot}303 \times log.\frac{d}{d'}}$$

Where R = the resistance coil already mentioned.

R' = the insulation-resistance of the cable, after an electrification for as long a time as the battery had been kept on before insulating the cable to observe.

R and R' being in megohms, the capacity will be in microfarads. (*Forde.*)

Testing for the Distance of Faults in Cables.

479. *When the conductor is bared, so as to make earth, but not broken.*—The length and resistance per knot of the conducting wire being known, it may be tested for earth from each end (353); but whenever a second wire is available to form a loop, the loop test (350) should be employed, as it is independent of the resistance of the fault, and is therefore more accurate than any other.

480. *Testing by the Balance.*—Place resistance coils in $a\ a'$ and $c\ c'$, connect the faulty wire to b', the good wire to d', and the earth to b or d; varying the resistance in $a\ a'$ and $c\ c''$ until a balance is obtained.[1]

[1] It has been thought better to explain the method by a reference to the parallelogram, although in practice the connections are more simply arranged.

The *resistances* of the portions of cable on either side the fault will bear the same proportion one to the other as the resistances in the arms opposite to them, that is, A : C : : B : D; and if, as is usually the case, the resistance of both the wires is uniform throughout, the *lengths* of the two portions of the cable will also bear the same proportion one to the other.

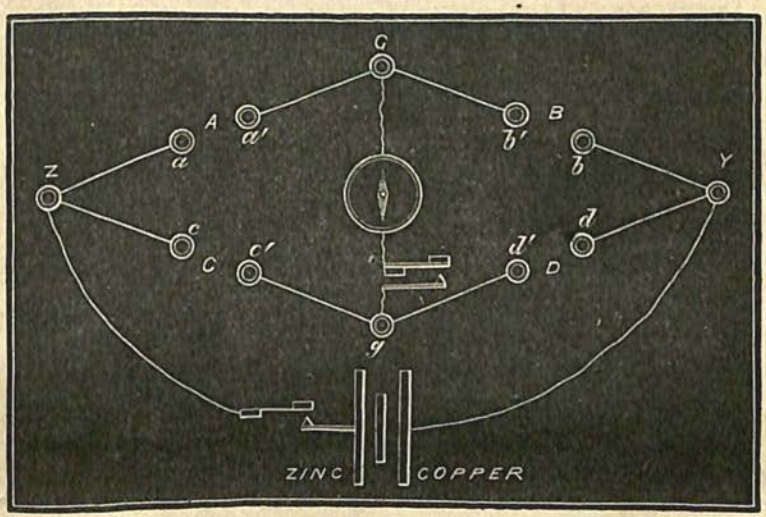


FIG. 111.

Thus the length of the loop in knots, which is known, is divided into two parts, bearing the same proportion one to the other that the resistance coil in A bears to the resistance coil in C.

Suppose, for example, that the length of the looped cables is 60 knots, that the resistance in A is 10, and that in C 15 ohms, or in the proportion of 2 to 3; then the shorter portion of the cable is two-fifths, and the longer portion three-fifths, of the entire length of the loop, so that the distance of the fault is $\frac{2 \times 60}{2+3} = 24$ knots.

Or generally, if l be the length of the loop in knots, a the

resistance in the arm A, and c the resistance in the arm C, $\frac{a\,l}{a+c}$ = the distance of the fault in knots.

Testing by the differential.—This method is fully explained at section 351.

481. *When the cable is broken.*—This is a much more difficult problem. When the cable is broken, both ends of the conductor are generally exposed, but occasionally one end is broken within the percha.

When the copper touches the iron the fault will offer little or no resistance, and its distance may be found by a simple resistance test.

But this rarely occurs, and there is considerable difficulty in ascertaining the distance, especially when only a short length of copper wire is exposed.

The difficulty of the problem arises from several causes.

(1.) As the ends are exposed, they form galvanic elements or batteries, with the iron sheath and the salt water, so that a + current flows from the cable, through the testing galvanometer, to earth; this is steady and constant if the cable is not disturbed.

(2.) We have to deal with two unknown resistances: that of the wire itself, and that between the exposed end and the earth; the first is constant, the second very variable, because

(3.) The action of the current alters the resistance at the point at which the metal touches the water, by coating it with substances of variable conductibility; and at the same time the apparent resistance is still further affected by the currents of polarization set up by these substances.

The action which takes place can be shown by placing a piece of cable in a glass filled with salt water, and applying a current from 40 or 50 cells, one pole of the battery being connected to the iron sheath, the other to the copper conducting wire. The portion of the cable connected to the zinc gives off a stream of

hydrogen, while the other becomes coated with a chloride of the metal. Thus, if the negative pole is connected to the conductor, and the positive to the sheath, chloride of iron is formed, and if the connections are reversed, chloride of copper is produced.

Let us now connect a galvanometer to the cable, in such a manner that the current from the cable battery of copper and iron in salt water, called the "cable current," shall deflect the needle to the *right;* the iron element being of course always on the earth.

If a negative current is now sent into the cable, its direction coincides with that of the cable current, and does not affect the direction of the deflection.

But the superior force of the testing battery overcomes the cable current, and polarizes its elements. The copper wire becomes coated with hydrogen, the iron sheath with chloride of iron, so that when the testing battery current is cut off, and the cable battery is again free to act, its action is reversed, and the needle moves to the *left*, under the influence of the current of polarization.

But the hydrogen gradually enters into combination and disappears from the wire, the polarization ceases, the needle returns towards zero, passes it, and finally takes up its former position to the right, under the influence of the cable battery in its normal state.

On the other hand, if we test with copper instead of zinc, the needle is deflected to the left, the cable battery again acts as a decomposition cell, but the polarization is now in an opposite direction, the copper being coated with its chloride, and the iron with hydrogen. When the testing current ceases, the needle therefore moves to the right, and continues permanently deflected in that direction, because the normal current from the cable battery is now in the same direction as the current of polarization.

If we apply a succession of short zinc currents, after the wire has been coated with chloride, the needle will take up a right-hand deflection after the battery contact has been broken; but the deflection will decrease after each test, and will finally be reversed. The deflection to the right is due to the polarization set up by the chloride of copper; each application of the zinc current reduces a portion of this chloride, and assists also in removing it mechanically by the action of the hydrogen; until after a time the chloride disappears, and is replaced by hydrogen. The sign of the polarization is then changed, and the direction of the needle changed also. But there is a moment when the opposite actions of the hydrogen and chloride are apparently balanced, so that the cable battery is inert, and the end of the wire unpolarized and probably uncoated. Then, and then only, can its correct resistance be determined. The object of the special method of test is to produce this condition.

482. *Lumsden's method.*—The test for distance is best made with a differential galvanometer. First ascertain the approximate resistance in the ordinary way, and clean the end of the wire from the dirt and salts with which it will be coated, by applying a zinc current for several hours, occasionally reversing it to get rid of any deposit of soda which may occur. The surface will be roughened by the re-deposit of the copper which has been dissolved, and will therefore more readily throw off the hydrogen evolved by the zinc current. Next, apply a positive current for the purpose of coating the wire with chloride of copper, and finally test with the negative current. The action of the current set up by the chloride of copper makes the resistance appear less than it really is; but as the chloride is gradually reduced by the testing current, in the manner which has just been explained, the resistance will appear to increase, moment by moment, and the resistance coils must be lengthened, unit by unit, to balance it, so as to keep the needle as nearly as possible at zero.

The increase of apparent resistance, and the consequent movement of the needle, is slow and gradual so long as the hydrogen is employed in reducing the chloride; when the reduction is nearly complete the movement is more rapid, and when the chloride has disappeared, the increase in resistance is enormous and almost instantaneous, and the needle moves over with a bound. Unless, therefore, the resistance of the cable has been carefully balanced, so as to follow the variation of the current throughout, the test will not succeed, because the neutral condition lasts too short a time to permit the adjustment of the resistance coils.

In the first stage of the test the motion of the needle is stopped, or even reversed, by adding one or two units to the resistance of the coils. But when the change is about to take place, this addition has no effect on the needle, and the coils will then show the true resistance of the cable.

In any case a certain dexterity is required, which can only be obtained by practice; but fortunately the practice may be had conveniently upon an artificial fault, or a piece of percha wire in a tin can, filled with salt water, and connected to a set of resistance coils. Induction does not affect the test, and as in any ordinary cable the insulation is practically perfect, its resistance can be represented as accurately by a rheostat as by an actual cable. The higher the tension of the battery, the less does the opposing current of polarization affect the result, for its force seldom exceeds two or three cells. The measurement is therefore made with a battery of as high a tension as can be conveniently procured, 60 cells or more.

The behaviour of a fault varies with the length of wire exposed; a short end polarizes and depolarizes very rapidly, its changes in resistance are correspondingly rapid and its resistance great. If the end is long, the changes are slower and are more readily observed; the resistance of the fault is also less.

After having well studied the changes of the fault itself, make

an artificial fault by placing a piece of the cable core in a tin can filled with salt water, and alter the length of the exposed wire until it behaves in the same manner as the cable, and then find its resistance, which will be very nearly the same as that of the real fault; so that the distance of the break will be the tested resistance of the cable less that of the artificial fault.

483. *Clark's approximate method.*—It is a convenient plan to form a table of the resistance of exposed ends of various lengths, with 6 and 60 cells, adding line resistance by a rheostat, using the negative current and allowing the end to take up its maximum resistance. The tests with 6 cells will be always higher than those with 60, that is to say, the resistance of the end will always appear higher when tested with the lower power, and the difference between the apparent and real resistance will also increase gradually, as the length of the cable itself or the resistance added by the rheostat increases, when the length of exposed wire is constant.

If a cable is found to give, with 6 and 60 cells, two results, corresponding to some two in the table, it is probable that the length and resistance of the end exposed is the same as that of the artificial fault used in the formation of the table, and therefore that the resistance between the testing station and the fault is equal to the resistance added to the artificial fault.

So much, however, depends upon the manner in which the tests for the tables were taken, or upon what we may call the "personal equation" of the observer, that every one should form a table for himself. The cable must be treated in precisely the same manner as the artificial fault, and therefore no table will be perfectly correct unless it is made just before the cable is tested, in order that the precise manipulation may not be forgotten.

The following table was formed with a piece of the Dunwich-Zandvoort cable, in a vessel of sea water, and shows the manner

in which the apparent resistance varies with the tension of the battery, the resistance added by the rheostat to represent the cable, and the length of the exposed wire.

Inches of copper wire exposed.		⅛		¼		½		¾		1	
No. of cells used.		6	60	6	60	6	60	6	60	6	60
Units of line added.	25	296	96	270	84	259	79	233	75	226	72
	50	325	121	299	109	287	104	261	100	255	98
	100	385	172	357	160	345	155	319	151	312	148
	150	443	223	416	211	403	205	376	202	369	199
	200	502	274	475	262	461	256	433	253	426	250
	250	561	325	533	313	519	307	489	304	482	301
	300	620	376	592	364	577	358	546	355	539	352
	350	679	427	651	415	636	409	603	406	596	402
	400	738	478	709	466	694	460	660	457	653	453
	450	797	529	767	516	752	510	716	507	709	503
	500	856	580	825	567	810	561	773	558	766	554
	1000	1440	1090	1406	1076	1392	1070	1339	1066	1332	1062

484. Temperature affects a distance test to a considerable extent by altering the resistance of the copper (80). Should the temperature of the sea vary only ten degrees, it would alter the resistance 2·1 per cent.

485. When a cable is broken, no current, beyond that which may be necessary to prove that the fault is in the cable, should be applied to it until it is tested from the shore. A newly broken end is clean and in a fit state for the operation, but the action of the sea-water quickly covers it with substances which interfere with the test, especially if a current is applied improperly, and it is, moreover, useless to test for distance through a land line.

486. If the fault is tested in the ordinary way before the exposed end has become coated, its proper resistance will be about two or three miles less than that shown by the test.

487. *Another method.*—The effect of polarization may be eliminated by applying a negative current for 10 or 12 hours, inter-

rupting it occasionally and giving a short positive current; watching the differential galvanometer to ascertain when the cable current ceases, then taking a resistance reading as rapidly as possible, and ascertaining whether the needle again comes to zero, showing that the polarization has not recommenced. It is necessary to adjust the resistance coils before the test, so that it may be made without loss of time; because if the polarization current be allowed time to establish itself, the test will be incorrect. The cable current is generally equal to one Daniell cell, and therefore the larger the number of cells used in testing, the more accurate will be the result. The final tests are made alternately with negative and positive currents, the *mean* of which is taken.

In a rapid tideway this test should be made at slack water, or the chloride may be washed off, causing the resistance to appear too great. If the conductor is a strand and the water penetrates to any distance under the percha, the first tests will be the best.

488. INDUCTION TESTS.—If one of the wires has very high resistance, or is broken within the insulating sheath, it is possible to *seal it up* by a positive current from 50 to 100 cells, continued 10 or 12 hours, so as to insulate it sufficiently to compare its charge and discharge with that from a known length of the same cable, or from a condenser of equal capacity (468).

In attempting to insulate the end, the current must not be interrupted for an instant, nor must it be *reversed*, for a reversal, however short, will destroy insulation.

489. *De Sauty's method.*—Place the cable in the balance (459) connecting the wire to b' and the earth to b, connect the inner coating of the condenser with d' and its outer coating to d, which will put it also to earth. Place resistance coils between $a\ a'$ and $c\ c'$, and put the galvanometer into circuit.

Charge the cable and condenser by pressing the battery key,

and vary the resistances in a a' and c c' until the needle remains unmoved, showing that the *inductive circuits*[1] B and D are equal. Then by the law of the balance, A : C : : B : D. If the condenser equals one mile of the cable, the distance is given in miles without further calculation; the length of cable represented by it being, in fact, the *unit* by which the distance is measured.

490. *Varley's method.*—Ascertain which takes the greater charge, the cable or the condenser. If it be the cable, connect it to one coil of the differential galvanometer, and shunt it by resistance coils; connect the condenser to the second coil of the galvanometer. By means of a key take charge or discharge tests, varying the resistance of the shunt until the needle is unmoved.

Then, let s be the resistance of the shunt,

g that of one coil of the galvanometer,

c the length of cable represented by the condenser,

l the length of the cable,

$$s : s+g : : c : l.$$

By the same method the length of a cable may be found from that of a similar cable of known length. Thus, if the length of the *shorter* wire be known, multiply it by $s+g$ and divide by s, which gives the length of the longer wire; or, if the length of the *longer* wire be known, that of the shorter may be obtained by multiplying the longer length by s and dividing by $s+g$, $\frac{s+g}{s}$ being the multiplying power of the shunt used.

[1] *Inductive Circuits.*—See Webb, "Electrical Accumulation and Conduction."

THE SPEED, OR CAPACITY FOR WORK, OF A CABLE.

491. The time required for a current to attain a given proportion of its maximum strength in submarine cables depends upon their length, their inductive capacity, and the resistance of their conductors.

(1.) The speed of a wave through cables of the same length varies inversely as the product of their inductive capacity and the resistance of their conductors.

(2.) In cables, similar in all respects except *length*, the speed of each, s and *s*, is inversely proportional to the *squares* of their respective lengths, l and *l*; or,

$$s : \mathrm{s} :: \mathrm{l}^2 : l^2.$$

For when the length is doubled, the capacity for charge, and therefore the charge itself, is doubled (466): and besides this, the waves of charge and discharge have twice the distance to travel, consequently the retardation is increased fourfold.

These laws may be expressed in the following manner:—

$$S = \frac{1}{L^2 R I}$$

Where L is the length of wire, expressed in knots; R the resistance of the conductor expressed in ohms per knot; I the inductive capacity of the cable expressed in microfarads; and S the speed.

(3.) In cables alike both in material and length, but differing in the *diameters* of their conductors, d and *d*, and insulators D and *D*:

$$s : \mathrm{s} :: d^2 \log. \frac{D}{d} : \mathrm{d}^2 \log. \frac{\mathrm{D}}{\mathrm{d}}.$$

(4.) When the lengths l and l are different also, then

$$s : \mathrm{s} : : \mathrm{l}^2 d^2 \log. \frac{D}{d} : \ l^2 \mathrm{d}^2 \log. \frac{\mathrm{D}}{\mathrm{d}}$$

(5.) Theoretically the time of charge is not influenced by a variation in battery power, but practically a stronger battery more quickly raises the current to a sufficient strength to affect the receiving instrument; and under certain systems of working, speed is increased by a slight defect in insulation.

492. When the diameter of the core is fixed, there is a loss in speed if the conductor is too small; because, although the coating is now thicker and the inductive capacity in consequence less, the increase of speed due to this cause is more than counterbalanced by the loss occasioned by diminished conductivity in the wire. On the other hand, if the conductor is too large, speed is lowered by increased inductive capacity in a greater degree than it is raised by lessened resistance.

There is therefore some proportion which gives the highest possible result, and it has been shown mathematically by Thomson that this proportion is attained when the diameter of the core being D, that of the conductor is $\frac{D}{1{\cdot}649}$, 1·649 being the square root of 2·718, the base of the Napierian system of logarithms. In this case log. $\frac{\mathrm{D}}{\mathrm{d}}$ is ·2172.

493. But practically, as Thomson shows, the insulator of such a cable would be so thin as to be very susceptible of injury, so that the diameter of the conductor must be decreased in order that the thickness of the coating may be increased. If it is desired to enlarge the dimensions, and the two diameters cannot be increased in proper proportion, it is better to enlarge the wire than the insulator. Hence the great advantage of greater purity of copper, which gives the benefits of a thicker conductor without its inconveniences.

The greatest proportional thickness of conductor is met

with in the Malta-Alexandria Cable, the ratio $\frac{D}{d}$ in which is 3·02; in the Atlantic the ratio is 3·18 and its logarithm $(\log.\frac{D}{d})$ ·502.

494. If we possess trustworthy data of the dimensions and speed of any existing cable, we may calculate those of any other, or construct a cable of any required working capacity.

But it must be premised, that in all calculations of speed it is supposed that the cables which are to be compared are worked precisely in the same manner; that is to say, if other things are equal the relative speeds will be those given by the formula. This is a condition which never can be obtained, except by using a mechanical transmitter, and hence the speed calculated from trials upon some well-known good cable, the Malta-Alexandria for instance, with a certain instrument and a certain clerk, frequently differ from the results obtained in practice, which in great measure depend upon the efficiency of the operator, and the skill with which the instruments are made and adjusted. Beside this, in short cables the maximum speed is seldom attained by hand keying.

495. *To find the speed of a cable whose dimensions are given from the known speed of another cable whose materials are similar but whose dimensions are different.*—Let it be required to calculate the speed, *s*, of 1,245 knots of the Persian Gulf Cable, from the speed of the Malta-Alexandria, which is said to be 6 words through 1,000 knots.

In the former cable $d = 110$, $\log.\frac{D}{d} = ·5383$, and $l = 1245$; in the latter $d = 153$, $\log.\frac{D}{d} = ·4808$, $l = 1000$, and $s = 6$. Then—

$$s : s :: 1000^2 \times 110^2 \times ·5383 : 1245^2 \times 153^2 \times ·4808 = 2·24,$$

the calculated speed of 1,245 knots of the Persian Gulf Cable, when worked in a similar manner to the Malta-Alexandria.

496. *To calculate the proper proportions of the core of a cable to provide for the transmission of a certain given number of words per minute.*—The Malta-Alexandria cable is assumed for calculation to give 6 words per minute through 1,000 knots. It actually gives 17 words through 597 knots, but by (2)

$$1000^2 : 597^2 : : 17 : 6.$$

Suppose that it is desired to construct a cable of 500 knots in length which shall give 10 words per minute. If we were to make use of the dimensions of the Malta-Alexandria Cable, 500 miles would give us 24 words per minute, for by (2)

$$500^2 : : 1000^2 : 6 : 24$$

We therefore can reduce the dimensions of the Malta-Alexandria core until we produce a cable of such dimensions that

$$L\,R\,I = L'^2\,R'\,I',$$

where the one side of the equation equals the dimensions of the Malta-Alexandria cable, and the other side those of the required cable.

In the above equation it is evident that $L = 775$, because by (2)

$$775^2 : 1000^2 : : 6 : 10$$

and therefore 775 knots is the length of the Malta-Alexandria core which would give 10 words per minute.

And as $\frac{1}{R\,I}$, or the reciprocal of the product of the resistance and inductive capacity of the Malta-Alexandria Cable is 129,[1] the equation becomes—

[1] The following are the dimensions of the Malta-Alexandria Cable, from whence $\frac{1}{R\,I} = \cdot129$ is derived.

Outside diameter of core = ·457 = D
Diameter of conductor = ·162 = d

Ratio $\frac{D}{d}$	log. $\frac{D}{d}$	$\frac{1}{\log. \frac{D}{d}}$	Resistance of conductor (R)	R I	$\frac{1}{R\,I}$
2·82	·4502	2·222	3·49	7·75	·129

$$\frac{775^2}{\cdot 129} = \frac{500^2}{x}, \text{ or } 775^2 : : 500^2 : : \cdot 129 : x;$$

therefore $x = \cdot 054 = \frac{1}{R\,I}$ for the required cable, and $R\,I = 18{\cdot}5$.

In the Atlantic Cable the ratio $\frac{D}{d}$ is 3·18 and its log. ·502, but if we made the ratio of the outside to the inside diameter of our cable 3·16, the logarithm of this or

$$\log. \frac{D}{d} = \cdot 500$$

$$\text{and } I \text{ or } \frac{1}{\log. \frac{D}{d}} = 2.$$

Again, as $R\,I = 18{\cdot}5$,

$R = 9{\cdot}25$, by substituting the above value of I.

Therefore the conductor of our cable must be a stranded wire whose resistance equals 9·25 ohms per knot.

Now, this would be a strand of ·102 in. diameter, and therefore we must make the diameter of our insulating covering such that

$$\log. \frac{D}{d} \text{ or } \log. \frac{D}{102} = \cdot 500.$$

D therefore is ·322 in. in diameter, so that a cable 500 knots in length, whose conductor measures ·102 in. diameter and gives a resistance of 9·25 ohms per knot, and whose insulating coating of gutta-percha measures ·322 diameter, will give us a speed of 10 words per minute, if worked in the same manner as the Malta-Alexandria. (*Preece.*)

497. In all experiments upon the speed of looped cables, or of looped land wires, when both ends of the circuit are brought into the testing room, it is necessary that two distinct earth connections be made, or very inaccurate results will be obtained.

498. *Difference in speed between a coiled and a straight cable.*—The introduction of automatic signalling instruments makes it

possible to compare the relative speed of transmission through comparatively short cables.

During the manufacture of the Dublin Cable in 1870, the highest speed at which *perfect* Morse signals could be produced with the Wheatstone apparatus, was ascertained while the cable was coiled in water in the tanks, and was found to be 45·8 words per minute through 52 knots. After the cable had been laid, a similar experiment was made by the same observers, and with the same apparatus. The speed was *increased* to 50·3 words through 57·9 knots, when the cable was straight instead of being coiled. It was also ascertained that with this apparatus, speed varied sensibly as the length and not as the square of the length of the cable; defining speed as the number of perfect Morse signals which it was possible to obtain in a given time.

METHODS OF WORKING CABLES.

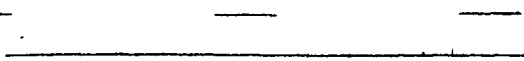
499. The speed of working is determined by the time required to cause a sufficient variation in the tension at the distant end to affect the receiving instrument.

As has already been shown (147), charge precedes current, and if the battery is cut off before the current has appeared at the distant end, the charge still travels onward. If the current is reversed at the sending end, the first charge still moves forward; while at the end nearest the battery it is met and neutralized by the reversed charge, which itself progresses. Thus a cable may be positive in one part of its length and negative in another, or even, if long, may be traversed by successive charges, either alike or of opposite sign, in the manner of *waves* (159).

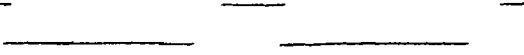
500. When a signal is sent through a cable, the current must complete its inductive action upon each successive portion of the outer coating before it can pass on to the next; as this occupies a sensible interval of time, a signal does not reach the end of a long cable till after a sensible interval. Some effect certainly is produced at the distant end as soon as the current is applied, but it is very feeble; the current gradually gains force until it reaches its maximum, when it remains constant, so long as the battery itself remains constant. If the tension of the battery alter, so as to cause the charge of the cable to increase or diminish, such change will require time for its accomplishment, because it also is accompanied by a change in the inductive effect.

The time required for the current received at the distant end of a cable to attain a certain proportion of its maximum strength, varies as the square of the length of the cable.

501. The effect of induction is, firstly, to retard the production of a signal, and secondly, to prolong it after the contact with the battery has been broken. If the cable is not put to earth at the battery end of the circuit between each signal, the effect of prolongation is at its maximum, for the charge can only escape at the receiving instrument. In this case, when dashes are sent, as shown by the upper of the two lines, a continuous line is produced, commencing a little late, thus—



When an earth contact is made at the sending end after each signal, so that the charge can escape at both ends, the prolongation is less, and the received mark shorter. The three dashes will then appear thus—



And if a reversed current is sent after each signal, so as to

neutralize a portion of the charge, the prolongation is still less.

The retardation or loss of time in the passage of the current is the same in each case, although the speed of signalling is greatest in the last.

The effect is best seen by using Bain's decomposing arrangement with two pens. Here a weakening of the line shows the gradual diminution of the tension of the charge until it becomes too feeble to decompose the solution. The gradual strengthening of the current can also been seen, but is not so evident. When a Morse or an ink-writer is used, the mark will obviously commence, and cease abruptly, as in the illustrations.

502. The cables between England and Holland, and England and Hanover, are worked by the Morse with reversed currents. The signals are produced by the positive current, and the negative current is applied in the interval between the signals to discharge the cable. But this negative current itself charges the cable, and must be discharged by the following positive current before the next signal can be recorded. It is therefore necessary to arrange that the negative shall be only just sufficient to *compensate* the positive, and it is found that the former should have about two-thirds the tension of the latter.

The ordinary hand-switch for changing the line wire from the key to the receiver cannot be used, because, to conform to the Continental practice, it is required that the clerks shall be able to *stop* one another during the slightest pause.

An automatic switch, technically called a *Zinc-sender* (Fig. 112), is employed, which consists of any polarized relay—Siemens', for instance—provided with two contact screws. The contact bar A has rather a wide play, and is fitted with a spring to lengthen the time of contact on the zinc side.

The coils have a resistance at least equal to that of the line and receiving instrument; the apparatus is connected as in Fig. 112. When the key is depressed the copper or marking current divides between the coils of the zinc-sender and the line wire, moving the contact bar A from the screw connected with the receiving relay to that connected with the zinc, thus joining the back stop B of the key with the zinc battery. When the key is released, the zinc current divides in like manner between the line and the coils of the zinc-sender, the one portion discharging the line, the other bringing the bar back from the zinc contact to the position for receiving signals from the distant station.

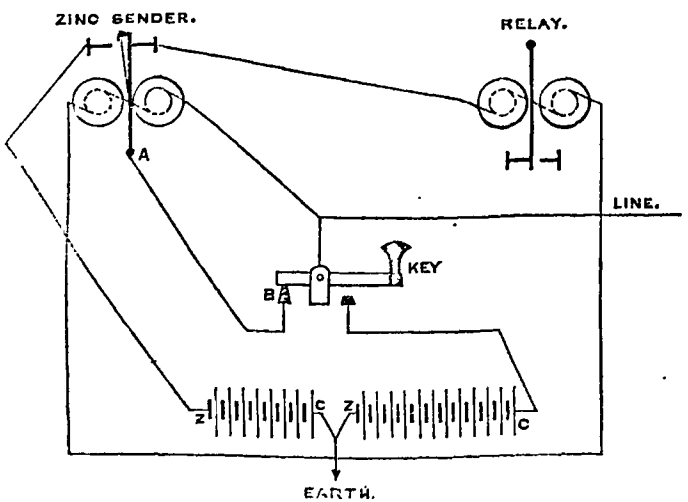


FIG. 112.

The contact bar A should be so adjusted as to be sufficiently attracted to the receiving side not to be acted on by the current from the distant station, or to be moved by the shaking of the table; and it should also *stick* sufficiently on the zinc side to remain there when the key is released until the key touches the back stop B, so as to permit the zinc to flow to line until the spring attached to the bar A has left the zinc contact screw.

The electro-magnet opposes for an instant the passage of the current, and therefore a larger proportion of current passes to line when a dot is sent than in the case of a dash. The derivation to earth assists in some measure in discharging the line.

This system is sufficient for cables under 300 miles in length, and where it is employed it is important that the resistance of the land lines connected to a cable, as well as that of the batteries and instruments, should be as small as possible, for the effect of adding resistance to either end of a cable is both to retard and weaken the signals. The effect of a given exterior resistance is greatest when it is equally distributed at either end, and least when placed at the receiving end of the cable.

503. It is not necessary, in order to produce a signal, that each wave should reach its maximum, nor that the cable should be fully discharged, but only that a sufficient *difference* should be caused in the tension at the distant end to affect the apparatus; the *apparent* speed will therefore depend on the sensitiveness of the receiving instrument.

When an ordinary relay or a Morse is employed, a signal does not commence until the current has attained sufficient strength to act upon the electro-magnet, nor does it cease until its force has diminished sufficiently to release the armature, so that a considerable difference of tension must be produced at the distant end of the cable; not only so, but the force must rise above and fall below a certain fixed zero point. But a reflecting galvanometer is capable of showing the minutest variation; it is infinitely more delicate than the most sensitive relay; and what is more important, it will indicate when the strength of the current varies in the slightest degree on *either side* side of zero, whatever be its absolute strength, provided the spot of light is kept on the scale. The speed of the mirror is therefore very much higher than that of the Morse.

504. *Method of working the Atlantic and other long cables.*—The

signalling apparatus, as arranged by Mr. Willoughby Smith, and now in use on the Atlantic cables laid between England and India, consists of the following parts:—

(1.) A very sensitive mirror galvanometer of simple construction, and of a resistance of about 2,000 units: the spot of light is thrown from the mirror on a shaded screen. A movement of the spot of light to the left indicates a dot of the Morse alphabet, a movement to the right a dash, as in the single needle code. These signals are produced by reversing the currents at the sending end by means of

(2.) An ordinary double sending key like that of a single-needle; and

(3.) A battery composed of a small number of the cells known as Minotto's.

As the receiving apparatus is extremely sensitive, it is important to avoid the disturbing effect of earth currents (183), and for this purpose a *condenser* having a capacity equal to that of 50 knots of the cable is placed between the cable and the *receiving* instrument, the sending-key being connected directly to the cable. The condenser is not inserted to increase the *speed* of signalling; in fact it slightly retards it; but it very materially assists in obviating interferences by earth currents.

It has already been shown that when one plate, or a series of plates, of a condenser is charged, the other being to earth, an equal quantity of electricity of the same sign leaves the opposite plate, returning when the charge is removed or reversed; and that if a galvanometer be placed between the second plate and the earth, it will be deflected for an instant by the passing of the electricity.

As the signals are thus given by short impulses, it is found occasionally necessary to introduce resistance into the circuit, to prevent too violent an action, or, as it were, to lengthen out the impulse. On long cables this is not necessary.

505. *Thomson's Ink-spirter* (so called).—The object of this

apparatus is to register signals similar to those of the reflecting galvanometer upon a paper ribbon. In it the coil is moveable and the magnet is fixed. A light coil of very fine wire is suspended between the poles of a powerful horse-shoe magnet, in front of the coil is placed an insulated vessel filled with common ink into which a syphon of extremely thin glass tube dips; the end of the syphon is bent horizontally and faces the paper ribbon; it is so arranged as to be free to move in a direction at right angles to the length of the paper.

Consequently, if the ink is caused to issue from the syphon with sufficient force and the syphon itself is moved from side to side, it will trace lines upon the ribbon.

If single-needle signals are sent through the circuit, the coil moves from side to side and moves the syphon by means of a thread connecting the two, and if the ribbon is caused to travel onwards, the movements of the coil will be recorded on the paper.

The spirting of the ink is necessary for the purpose of avoiding friction on the surface of the paper, and is effected by electrical repulsion, the ink vessel being charged to a high potential by means of a *doubler* driven by an electro-magnetic engine.

506. Many arrangements have been proposed for discharging a cable rapidly; among which is *the curb-key* which was designed for the Atlantic Cable.

When a current is sent into a cable the effect is prolonged by induction, and the signal in consequence lasts too long; in working in the ordinary method a reversed current is used to shorten its effect, as has already been explained. But this current is prolonged also, and itself requires correction by a third current in the same direction as the first, and so on. Five alternate currents, of the following respective durations and signs, were considered necessary for the Atlantic, $+ 100 - 156 + 80 - 32{\cdot}5 + 26$, the resultant of which is a short positive signal, of a strength equal to one per cent. of

that current which the battery would produce if placed permanently in circuit; the second current is stronger than the first, in order that it may act as rapidly as possible. The duration and direction of the currents are regulated mechanically.

507. The influence of the *extra current* from a coil, and more particularly from a coil containing iron, as an electro-magnet, in retarding and mutilating telegraph signals, should be particularly taken into account in telegraphic arrangements. The disturbing effect of electro-magnets is more particularly evident when they are introduced in the circuit at or near the sending end of a submarine cable, on account of the comparatively large amount of current required for the first portion of each signal, and the consequent greater practical effect of any disturbing cause. Any cause tending to alter the magnetic condition of the iron will cause a corresponding variation in its disturbing influence upon signals, so that an armature placed before the poles of an electro-magnet, or arranged to be attracted by it, as in a relay, will increase the interfering effect; and the amount of this interference will vary with the distance of the armature, the maximum disturbing influence being produced when the armature is in contact with the cores, and diminishing rapidly according to the distance to which it is removed from them. The greater the mass of iron in the cores, the heavier the armature, and the more sluggishly it moves towards the electro-magnet, the greater the effect upon the signals. Several Morse instruments introduced into the same circuit will interfere to some extent with each other, independently of any retardation consequent upon the length or other conditions of the conductor, and the armatures will not be attracted at the same instant.

The effect of an electro-magnet introduced at the sending end of a line, more particularly if the latter be a submarine cable, is to shorten the signal considerably, or to entirely prevent its transmission, for until the iron has become magnetized no signal will be sent. The effect on a longer signal than a dot will be to

shorten it, but in a less ratio. When a dash or several dots in succession are sent through the coils, the iron, retaining a portion of its magnetism after each break, will have a different effect on each succeeding current, so that compensation is almost impossible, and the signals at the receiving station will exhibit the greatest irregularity.

A polarized relay, such as Siemens', has less effect than an ordinary electro-magnet, because the variation of magnetism is less and the extra current feebler. The less the resistance of the wire surrounding the iron or the shorter the coils of a galvanometer, the smaller the disturbing effect. A galvanometer of many turns has a sensible effect if introduced at the sending end of a circuit, while a Morse wound with No. 30 wire, and of comparatively few turns, has but a slight effect. Probably if the coils were shunted so as to afford a path for the extra currents, the disturbing effect would be lessened.

TESTS USED DURING THE LAYING OF CABLES.

508. For cables not exceeding 200 or 300 miles in length the following plan may be adopted:—When there are several wires in a cable, they are looped together into a continuous length. If the number is even, an instrument is placed on shore, in one of the loops, for the purpose of communicating with the ship. The junctions of the several wires on shore are carefully sealed, and the instrument is fixed on a well-insulated stand. This is to make certain that the insulation test shall not be interfered with. If the number of wires is odd, one of them is set apart for communicating.

All tests are made by the ship, and the shore may not speak or send a current unless by permission of the ship.

The wires being looped, a small battery and an ordinary

vertical galvanometer, both well insulated, are connected between the two extremities. The galvanometer remains permanently deflected, and serves as a test for continuity, without interfering in any way with the insulation test.

For insulation, a battery of 100 cells or more is connected, one pole to earth, the other to the stud marked B of the trigger key (Fig. 109), the opposite stud G being to earth.

The lever of the key is connected to cable through a marine galvanometer. When the lever of the key rests on the battery stud, the cable is under test for insulation or being charged; if the lever is released, and allowed to fall back to the opposite or earth stud, the cable is discharged through the galvanometer. But before charging or discharging the cable, the vertical galvanometer must be short-circuited, or it may be demagnetized.

509. The following plan has been proposed for maintaining a constant continuity test at the same time with the usual insulation test in a single wire cable.

The battery and galvanometer for the insulation test are placed on the ship, and the land end of the cable is connected to an insulated spring. A pendulum is made to vibrate between this spring and a similar one connected to earth through a galvanometer. The bob of the pendulum contains a condenser, which, by vibrating between the end of the cable and the galvanometer, alternately charges itself from the cable and discharges itself through the galvanometer.

The intermitting contacts with the condenser would appear on the ship's galvanometer like slight contacts with earth, and the shore needle would indicate the passage of intermitting currents, so long as the cable remained perfect. The currents would gradually lessen and finally cease if the wire parted inside the percha, so as to become insulated, and would cease suddenly if the broken end were exposed, so as to allow the charge within the cable to pass to earth.

510. But for long single-wire cables a more refined method is required. The system adopted for the Atlantic and all other recent long cables, is that of Mr. Willoughby Smith.

It is first necessary to describe the Resistance Slides.

Resistance slides.—These are used in order to charge a condenser to a certain fraction of a given potential, or to vary its charge to balance the varying charge of a cable.

It has already been shown that when one pole of a battery is put to earth and the other pole is connected to a wire of high resistance, such as a long telegraph wire, the distant end of which is also to earth, the potential (tension) falls regularly along the wire, becoming zero at the distant end, and the potential of any point can be ascertained by an electrometer of sufficient accuracy.

It therefore follows that if a divided scale be attached to such a wire, a condenser may be charged to one-half, one-tenth, or any given fraction of the maximum potential of the battery, by connecting it at the proper point.

An artificial line is constructed by a large number of resistance coils. If there be 100 coils all equal in resistance (100 ohms each), the potential will vary by $\frac{1}{100}$th part at the junction of each pair, and thus, by attaching a condenser to any junction, it may be charged to any fraction of the total potential of the battery within $\frac{1}{100}$th part.

If a second similar set be connected between any two coils of the first, the difference of potential between these coils will again be subdivided into 100 parts, and thus a reading of $\frac{1}{10000}$th may be attained. This arrangement is mentioned also at p. 285.

511. *Tests during the laying the Atlantic Cables.* — Fig. A represents the arrangements for the shore, and Fig. B those for the ship. (See diagram.)

Shore tests.—In Fig. A the end of the cable is shown as connected with a switch S, which can be made to touch either of the three terminals marked 1, 2, 3. It is usually connected with 1. The cable end is also permanently connected through

a high resistance (20 or 30 megohms), to a galvanometer G, and thence to earth.

When a permanent current is sent from the ship's testing battery, the end of the cable being almost perfectly insulated is raised to a high potential, but sufficient current will leak through the resistance to affect the mirror galvanometer G. The resistance should be adjusted so as to allow a deflection of about 200 divisions on the scale of G.

But if the cable conductor become broken, or bared in the slightest degree, a much feebler current or none at all will pass the resistance; this arrangement then serves as a continuity, and also for an approximate insulation test for shore.

This high resistance is not an ordinary coil, but is made of selenium or of percha, and its permanence is not well assured. A second means is therefore provided by which shore can ascertain whether the potential of the cable is maintained. Terminal 1 leads to the back stop of a key K, the lever of which is connected to the upper plate of a condenser C, whose lower plates are connected through a galvanometer G^1 to earth. When this key is depressed, it discharges the upper plates to earth and produces a deflection on G^1.

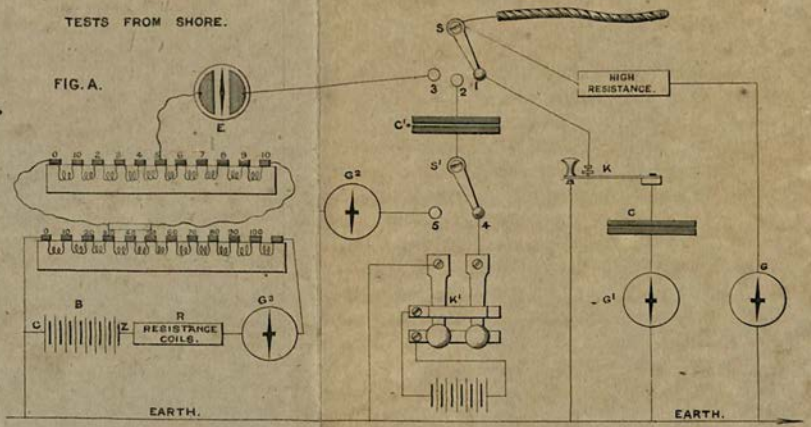
But, as the upper plates are permanently in connection with the cable when the key is at rest, the condenser is charged to its potential, so that the discharge and deflection consequent on pressing the key shows the potential of the cable for the time being. This test serves as a check upon the first.

When it is desired to converse with the ship, the switch S is moved to terminal 2, leading to the upper plates of a second condenser C^1; the lower plates of which are connected to a second switch S^1, which can itself be brought into contact with one or other of the terminals 4 or 5, leading to a reversing key K^1, and a galvanometer G^2 respectively. To receive from the ship the switch S^1 is turned towards G^2; when any alteration in the potential of the cable is communicated to the condenser

ATLANTIC AND OTHER LONG CABLES.

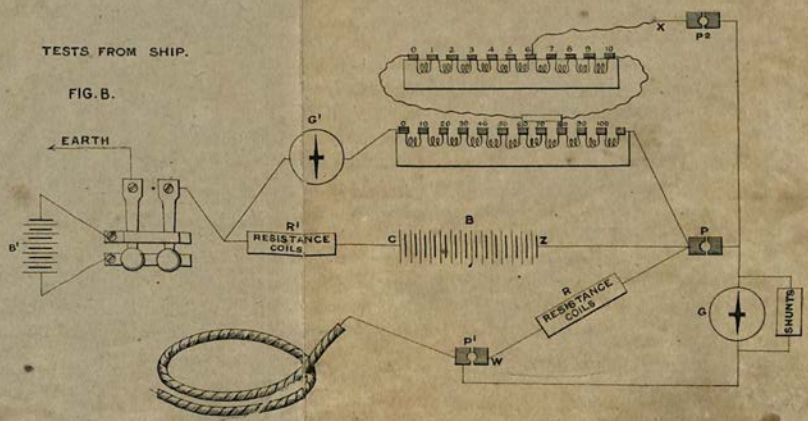
TESTS FROM SHORE.

FIG. A.



TESTS FROM SHIP.

FIG. B.



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C^1, and is indicated by a movement of the galvanometer needle, either to the right or left, according to whether the charge is raised or lowered, by the reversing key on the ship.

To speak to the ship, S^1 is moved to terminal 4, leading to a reversing key, which by charging the lower plates of condenser C^1, either positively or negatively, raises or lowers the potential of the cable, and produces single needle signals upon the ship's galvanometer G (Fig. B).

It will be seen that during signalling the insulation of the shore end of the cable is unaffected, all the signals being produced by induction through the condensers.

Again, if the switch S is turned to terminal 3, it is connected to one side of a reflecting electrometer E, the other side of which is connected to a set of the slides already described, by means of which the electrometer can be charged to any required fraction of the potential of the testing battery B. If then the slide is moved until the electrometer stands at zero, its position on the resistance coils will show exactly the potential of the cable in terms of the testing battery.

But it is necessary to eliminate the error which would arise from a variation in the testing battery, and for this purpose a set of ordinary resistance coils R, and a third galvanometer G^3, are provided. The resistance of these coils is from time to time altered so as to keep the potential of the slide, as shown by the deflection of G^3, uniform; so that its indications may remain perfectly constant from day to day.

Thus if the minutest fault occur, the time of its occurrence can be ascertained and its locality calculated.

Ship tests.—It is desirable that the tests on board the ship should be less complicated than those on shore, and they are consequently arranged in the more simple form shown in Diagram B. They consist of a Wheatstone's bridge, in connection with battery B, one pole of which is connected with the point Z, from which, the plug P being out while the plugs P^1 and P^2 are

in, the current will be divided and pass; a part by the resistance coils R, to the point W, and a part through the right-hand section of the slide and coils to the point X, forming two sides of the bridge—the other two being represented by the resistance of the insulating sheath of the cable, and the left-hand section of the slides. When the plugs P^1 and P^2 are in, there is also a circuit from W to X, through the galvanometer G, completing the combination. Now the shore extremity of the cable being always insulated, the means of determining the insulation of the cable itself are very simple: the galvanometer G will of course indicate when the resistances in the four sides of the Wheatstone's bridge are balanced, under which circumstances they will form a simple proportion, of which three of the factors, viz. the resistance in the coils R and the right and left sections of the slide, are known, and from which the fourth, the resistance of the insulation of the cable, can be found.

The resistance of the coils R is not altered, but the galvanometer G is brought to rest by the adjustment of the moveable part of the slides. If any injury causing a leak should occur in the cable, the Wheatstone's bridge will have to be used in determining the position of that leak by simply balancing the resistances, as already described, when the difference of resistance in the cable thus determined will, in conjunction with the observation at the shore end, give the required data for calculating the position of such leak with considerable accuracy.

If anything should go wrong with the Wheatstone's bridge, there is still the means of applying the direct insulation test, by simply removing the plugs P^1 and P^2 and inserting the plug P, when the current escaping through any leak will at once indicate on the galvanometer G, the deflection of which will under such circumstances be largely increased.

The resistance coils R^1 are arranged, in connection with the galvanometer G^1, to regulate the potential of the battery B, in

the same manner as the resistance coils R, and galvanometer G^3 (Fig. A), are used for regulating the potential of the battery B in the shore arrangement. Battery B^1 (Fig. B) is used, in connection with the inverting keys attached thereto, for speaking to the shore: by pressing one or other of the keys, the potential of B^1 is added to or subtracted from that of B, so as to alter the charge in the cable.

It is necessary to render the galvanometer G (Fig. B), extremely sensitive when the insulation test is made, in order to ensure as fine a balance as possible in ascertaining that insulation; whereas when signals are to be received by it, its sensitiveness has to be reduced to keep the vibrations of the spot of light within certain limits; for this purpose it is supplied with a shunt, as shown in the diagram. Between every letter the galvanometer G is rendered very sensitive, and an insulation reading taken; but practically the insulation test is never off, for if any considerable fault occur during the process of speaking, the shore end of the cable being always insulated, and that on board ship in connection, through the galvanometer and slides, with the battery, the leakage of the current will produce a very considerable change in the indications of the galvanometer G, a far greater change than could possibly be produced in transmitting the signals.

It will be perceived that during the whole process of submergence the shore end of the cable is always insulated, and the tests are never removed either for signalling or any other purpose: this continuity of the tests is the great advantage of the system.

The foregoing has been, in the main, condensed from the very excellent lectures given by Professor Fleeming Jenkin to the Royal Engineers at Chatham, and it describes the system adopted during the laying of the 1866 Cable.

Mr. Willoughby Smith explains that the slides and battery in connection with the electrometer in the shore arrangement

were used at the request of Sir William Thomson, merely as an experiment. But no trustworthy results were obtained by the arrangement, and therefore during the laying of the French Atlantic, the slides and battery were not used on shore, but the electrometer was permanently connected between the end of the cable conductor and the earth, as a check on the condenser system for obtaining the potential of the line. In all the long cables laid since the French Atlantic, the condenser system *pure* and *simple*, without the electrometer, has been adopted with very satisfactory results.

512. *Measurement of capacity in short pieces of cable.*—It is often necessary to measure the capacity of short lengths of wire, small condensers and samples of insulating materials, the charge and discharge from which are far too feeble to affect a galvanometer, even if a powerful battery is employed.

But although a single discharge is unable to affect the galvanometer, a succession of discharges following one another so quickly that the needle has not time to regain its zero before a fresh impulse is given it, will each move the needle a certain distance, and the sum of their effects will produce a steady deflection. The value of a single discharge can be found by dividing the deflection at the end of a given time by the number of discharges.

The apparatus for this purpose is called a "whip," and in its simplest form is a spring, connected to the condenser to be measured, which is caused to vibrate very rapidly between two studs, one in connection with the battery, the other with the galvanometer. As the spring vibrates it first charges the condenser from the battery, and then discharges it through the galvanometer to earth. (See also 467).

513. *Application of the principle of* compound interest *to calculations respecting variation of resistance* arising from alteration of temperature, and the fall of tension.

If the resistance of an insulated core or of a copper wire be

increased at a certain rate per cent. by a rise of one degree of temperature, it will be increased by the next degree of rise at the same rate per cent. calculated upon the new resistance, not upon the original resistance. Thus if the original resistance at the commencement of the experiment represent the principal; the rate of increase, the rate of interest; and the new resistance after the temperature has been raised one degree, the amount or sum of principal and interest after the first year; the increase due to the elevation of temperature a second degree will be equivalent to the interest for one year on the new principal, and so on. Conversely, the diminution of resistance caused by a fall of temperature obeys the law of discount in money.

This law enables us to construct tables for the reduction of readings of resistance or insulation to the standard of 75 degrees, and for the calculation of the reading at any temperature from a test made at any other.

To construct a table for copper (Table XIII.), first find by trial the resistance of a coil of known length and diameter, at two temperatures, as widely apart as possible.

Let R be the resistance at the higher temperature,

r that at the lower temperature,

n the difference in degrees between the two,

and p one unit of resistance (one ohm), plus the increase of resistance due to a rise of one degree Fahrenheit; that is to say, the sum or amount of principal and interest for one year.

Then $$(1)\ \log. p = \frac{\log. R - \log. r}{n}.$$

From this the resistance r' at any other higher temperature may be found by

$$(2)\ \log. r' = \log. r + n' (\log. p),$$

where n' is the difference in degrees between r and r', or between the lower of the two former temperatures and that

whose corresponding resistance is sought. For example, having found by experiment that the resistance of a knot of pure copper wire is

1091·22 ohms at 32° Fahrenheit
1156·03 „ 60° „

we require to find its resistance at the standard temperature, 75° Fahrenheit.

Here $R = 1156{\cdot}03$
$r = 1091{\cdot}22$
$n = 38°$

and we have by (1)

$$\frac{\log. 1156{\cdot}03 - \log. 1091{\cdot}22}{28} = {\cdot}0008950 = \log. p.$$

Again, as $n' = 75 - 32 = 43°$, by (2)

$$\log. r' = \log. 1091{\cdot}22 + 43° ({\cdot}0008950) = \log. 1192{\cdot}33.$$

1192·33 ohms is therefore the resistance at 75° Fahrenheit.

To form a table of the resistance of the wire for each degree, log. p is determined by (1). Then taking log. r as the log. of the resistance at the lowest temperature, log. r + log. p = the log. of the resistance at the first degree of increased temperature, and again by adding log. p to the log. of this new resistance, we obtain the log. of the resistance at the second degree, and so on. From the table, when formed, the resistance of any coil may be found by proportion.

But it will be found by an inspection of formula 2, that the log. of the difference in resistance at any two temperatures is always log. p multiplied by the difference of temperature, or that if we want the resistance (r') due to a rise of 10° we may say—

$$\log. r' = 10 \log. p + \log. r.$$

Therefore, if we multiply log. p by 1, 2, 3, 4, and so on, we obtain a series of logs., the numbers corresponding to which

form a new series of co-efficients by which the resistance of any copper wire may be multiplied to find its new resistance at an increase in temperature of 1, 2, 3, or 4 degrees, and their reciprocals will be applicable to a scale of decreasing temperature.

For example, the resistance at 32° was found to be 1091·22,

The log. of which is . . .	3·0379124
Log. p is	·0008950
The sum is	3·0388074

which is the log. of 1093·47, the resistance at 33°, and as the log. of

The resistance at 33° is . .	3·0388074
By adding log p	·0008950
We obtain.	3·0397024

the log. of 1095·72, the resistance at 34°.

For example, the resistance of our coil at 32° is 1091·22, and log. p is 000·8950. The co-efficient for 28° the difference between 32° and 60°, is the number corresponding to 28, log. p, or 1·0594, and therefore 1091·22 ... 1·0594 = 1156·03, the resistance at 60°.

Again, to apply the co-efficient to the determination of temperature from resistance, we know that when the resistance of our coil is 1091·22 the temperature is 32°, and if on making a second test we find the resistance is 1156·03, and desire to know the temperature, we say $\frac{1156·03}{1091·22} = 1·0594$, which, on reference to the table of co-efficients (Table XIII.), we find opposite a difference in temperature of 28 degrees. The temperature is therefore 32 + 28 = 60°.

The same reasoning applies to the effect of temperature upon insulation, and to the fall of tension.

514. *The Wave-Discctor.*—The determination of the relative speed of cables by the number of words per minute which can be sent by an ordinary Morse apparatus is very unsatisfactory, because so much depends upon the individual skill of the *operator* and the perfection of the apparatus.

It has therefore been proposed to use a more definite standard, or to calculate the *speed of a wave* by mechanical means. For this purpose Siemens uses a *wippe,* and Varley a rotating commutator. In the latter, two brass discs A and B are placed upon the same axis, but are insulated from it. Each disc is also divided into two insulated halves, the divisions being exactly in the same line. The halves of A are connected to the two poles of a battery, the halves of B to the two terminals of a galvanometer, wound with a thick wire, and having somewhat heavy astatic needles delicately suspended. Contact springs are fixed on opposite sides of each disc, pressing upon its edge; those on one side each disc are connected to earth, those on the other to the two ends of the cable. Thus when the discs are made to revolve, A sends alternately positive and negative currents into the cable, while B reverses the connections of the galvanometer at the distant end (B) of the cable at the same instant the current is reversed at A. This being so, if a short wire is used to connect A and B the speed of the current will be infinite, and the needle will be deflected uniformly to the same side, because the force acts always in the same direction. But if a condenser or cable be placed between A and B (the current will be retarded, and will occupy a sensible time in passing through the cable from A to B), it will not be reversed at the receiving end, B, at the same moment that it is reversed at the sending end, A, so that more current will flow through the galvanometer in one direction than in the other, and the needle being acted on by two opposite but unequal forces, will take up a smaller angle of deflection, obeying the greater of the two.

But by increasing the speed of the machine until the wave

is bisected—that is, until the galvanometer connections are reversed at the moment the received current has attained half its duration—the galvanometer will receive, *after* it is reversed, a current equal in strength to, and of the same name as, that which passed through it *before* it was reversed, but it will pass in the *opposite direction*, so that the needle being acted on equally in both directions, will remain steady.

The longer the wave the greater the retardation, and consequently the slower the rate of rotation to measure it.

This apparatus, however, gives only relative results, but they are evidently far more uniform than those obtained by the key. The law of the squares (491) can easily be verified by it.

MISCELLANEA.

515. THE value formerly assigned to the *Farad* has now been given to the *Microfarad*, the latter being the thousandth part of the former.

Chatterton's Compound:—

1 pound Stockholm tar,
1 „ resin
3 „ gutta-percha.

Ratio between circumference and diameter of a circle . .	3·1416
Ratio between area and diameter of a circle	·785
Specific gravity of pure copper (*Miller*) . . .	8·921 to 8·952
„ „ cable copper (*W. Smith*)	8·899
„ „ iron (*Miller*)	7·884
„ „ percha (*Clark*)	0·981

Weight of Cable Cores.—The following empirical data may be found sometimes useful for calculating the approximate weight

of cores. 64 circular mils (thousandths of an inch) in sectional area of copper, 69 circ. mils of copper strand, 63 circ. mils of iron, 481 circ. mils of gutta-percha, or 401 circ. mils of Hooper's material, weigh one pound per knot. Hence $\frac{d^2}{54}$ gives the weight per knot of any solid copper conductor, and $\frac{d^2}{69}$ of any copper strand; and similarly, $\frac{D^2 - d^2}{401}$ gives the weight of Hooper's material, and $\frac{D^2 - d^2}{481}$ the weight of gutta-percha in any core; $\frac{d^2 n}{6789}$ gives the weight of iron in cwts. per knot (including lay) for any cable of n wires. (*Clark.*)

Soldering.—Connections in apparatus and test-boxes must never be soldered with acids or chloride of zinc. If spilled on wood, or even on ebonite, chloride of zinc never dries, and injures the insulation. Rosin must always be used.

APPENDIX AND NOTES.

516. *To measure the relative magnetic force of horizontal needles, or of currents acting upon them, by the* time *occupied by the needle in performing a fixed number of vibrations.*

A. *To compare the strength of magnets:—*

When magnets are caused to vibrate, they obey the laws of the pendulum, and the forces acting upon them are *inversely* as the times of vibration, or *directly* as the reciprocals of the times. The stronger the magnetism of the needle, the greater will be the effect of the directive force of the earth upon it, and the faster will it vibrate.

Thus, if a needle A make 20 vibrations in 10 seconds, and another needle B the same number in 5 seconds, A : B : : 5^2 : 10^2; or B is four times as powerful a magnet as A.

B. *To compare the strength of currents:—*

Place a horizontal galvanometer east and west, so that the needle is at right angles to the coils, in which position a current will have no effect upon it.

Cause the needle to vibrate under the influence of the earth's magnetism only, that is, without any current in the galvanometer; note the number of seconds during which the needle makes a fixed number of vibrations, and call this time n.

Now cause a current A to flow through the coils of the galvanometer, and repeat the above operation, noting the number

of seconds in which the same number of vibrations is made; call this time H.

Substitute another current, B, and again note the number of seconds, which call N.

The forces acting upon the needle in the above three experiments will be in the proportion of

$$\frac{1}{n^2} \quad : \quad \frac{1}{H^2} \quad : \quad \frac{1}{N^2}$$

In the two latter cases there are two forces acting upon the needle, the earth's magnetism and the current; the former is constant for the same locality, and may be considered as unity.

The formula $\frac{n^2 - H^2}{H^2}$ will give the correct value of the force A in terms of the earth's magnetism considered as unity. For the force B, the formula would be $\frac{H^2 - N^2}{N^2}$.

If, in the three experiments described above, the times are 20, 10, and 5 seconds respectively, then the value of the current A will be $\frac{20^2 - 10^2}{10^2} = \frac{400 - 100}{100} = 3$,

and of the current B, $\frac{20^2 - 5^2}{5^2} = \frac{400 - 25}{25} = 15$;

therefore, the current B has five times the strength of the current A.

517. *To arrange a "shunt" on Wheatstone's principle, for reducing the sensibility of the galvanometer, by leading away part of the current through another circuit.* (127, 308.)

If a current be split between the wires of the galvanometer and a wire attached to its two terminals, called a "shunt," it is evident that it will divide itself between them in the inverse proportion of their resistances. If the shunt be exactly equal in resistance to the galvanometer, the current will divide equally, and the deflection will be exactly one-half of what it was with-

out the addition of the shunt. If the shunt be one-half the resistance of the galvanometer, two parts will flow through the former and one through the latter; the deflection will then be one-third, and must be multiplied by three, to compare it with the deflection given by a wire tested without the shunt, and so on.

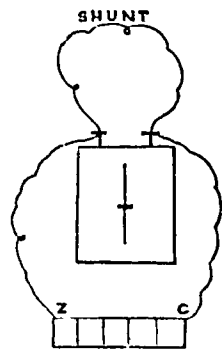

FIG. 113.

This is perfectly correct where the resistance of the line tested is considerably greater than that of the galvanometer and battery, but it is not so for short lengths. For when the shunt is used, the resistance of the circuit being lessened, the battery acts more powerfully, more current passes out to line, and the deflection is proportionately increased.

It is therefore necessary to add to the line, that is, to introduce between the line and the galvanometer a resistance which will compensate for the reduction of resistance caused by the addition of the shunt, thus making the resistance of the testing apparatus, including galvanometer, shunt, and compensating wire, the same as that of the galvanometer when no shunt was used. (*De la Rive*, "*Treatise on Electricity*," vol. ii. note B.)

Calculate the resistance of the galvanometers *with* the shunt by the usual formula, and subtract it from the resistance of the galvanometer itself *without* the shunt; the difference will be the length of the wire required to compensate the circuit.

Thus, to halve the deflection of a galvanometer of 10 units, resistance, the shunt must be 10 units, and $\frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5$ units, which will be the resistance of the galvanometer with the shunt attached.

Subtract 5 from 10, the remainder, 5 units, will be the length of the compensating wire to be added to make the *total resistance of the whole circuit* the same as when the shunt was not used.

Again: if the shunt equalled 5 units, $\frac{10 \times 5}{10 + 5} = 3{\cdot}33$ units, then 6·67 units would be required to bring up the resistance to 10 units, as at first.

In telegraphy, the compensating wire is never required.

TABLE.

Amount to which the deflection is to be reduced.	Resistance of shunt required.	Resistance of compensating wire.
To $\frac{1}{2}$	Equal to galvanometer.	Half of galvanometer.
,, $\frac{1}{4}$	$\frac{1}{3}$ of do.	$\frac{3}{4}$ of do.
,, $\frac{1}{8}$	$\frac{1}{7}$ of do.	$\frac{7}{8}$ of do.
,, $\frac{1}{10}$	$\frac{1}{9}$ of do.	$\frac{9}{10}$ of do.
,, $\frac{1}{100}$	$\frac{1}{99}$ of do.	$\frac{99}{100}$ of do.
,, $\frac{1}{1000}$	$\frac{1}{999}$ of do.	$\frac{999}{1000}$ of do.

The rule for ascertaining the *resistance* of a shunt intended to reduce the sensibility of a galvanometer to any required fractional part, is readily deduced from an inspection of the table. The *multiplying power* or *value* of a shunt, that is, the number by which the indications of a shunted galvanometer must be multiplied to render them equal to the indications of the same galvanometer without the shunt, is $\frac{g+s}{s}$, or $\frac{g}{s} + 1$ where g and s represent the respective resistances of the galvanometer and shunt. For let e be the electromotive force of the battery, e' the portion of the current which passes through the galvanometer. Then $e - e'$ will be the portion passing through the shunt. These two quantities will be in the inverse ratio of the resistances of the circuits, thus—

$$g : s : : e - e' : e'$$

whence $\frac{e'}{e} = \frac{s}{g} + 1 = \frac{s}{g+s,}$ being the proportion of the

battery current passing through the galvanometer, the reciprocal of which, $\frac{g+s}{s}$, is the factor by which the indications of the shunted galvanometer must be multiplied. Conse-

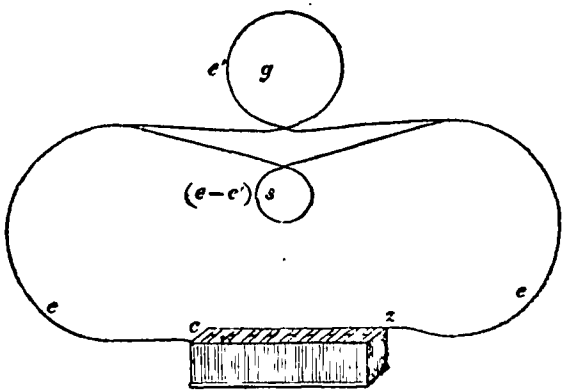

FIG. 114.

quently, when two forces are compared by shunting a galvanometer until the indication given by the greater is reduced to that given by the lesser, the former will exceed the latter $\frac{g+s}{s}$ times.

A delicate galvanometer may thus be adjusted so as to measure powerful currents.

518. *To construct a correct scale for an ordinary detector or a horizontal galvanometer* (122) :—

(1.) Find the resistance of the galvanometer and of the battery employed, and, by means of the rheostat, adjust the resistance of the circuit till the needle marks 10° on the scale.

(2.) Halve the *total* resistance of the circuit; the force acting on the needle will now be doubled. Mark the deflection as 20°.

(3.) Again halve the resistance; the deflection will once more be doubled, and may be marked as 40°; and so on.

Suppose the battery resistance be	1	ohm.
That of the detector	10	„
And the resistance added to reduce 10° . .	109	„
The total resistance will be	120	

To double the force acting on the needle, one-half 120, or 60 ohms, must be removed from the circuit.

When the resistance of the detector and rheostat is very much greater than that of the battery (as for instance when one large cell is used), the battery resistance may be disregarded.

519. *To find the resistance of a battery:—*

When the entire resistance of a circuit, including a galvanometer, is *doubled*, the deflection, which is proportional to the tension of the battery divided by the resistance of the circuit, will be *halved*. Connect a sine or a tangent galvanometer of known resistance on short circuit with the battery to be measured. Reduce the sensitiveness of the galvanometer, if necessary, by a shunt, and note the sine or tangent of the deflection. Add extra resistance until the sine or tangent of the deflection is exactly halved, showing that the *total* resistance of the circuit has been doubled. Deduct the resistance of the galvanometer and connections (allowing for the shunt) from the *extra resistance added*, the remainder will be the resistance of the battery.

For instance, if the galvanometer and connections have a resistance of 50 ohms, and the addition of 70 ohms be required to halve the sine or tangent of the deflection, the battery resistance will be 20 ohms.

520. *To compare E, the electromotive force of batteries:—*

(1.) Connect the battery with a galvanometer, and introduce resistance until a deflection, say of 30°, is obtained. Intro-

duce more resistance until the deflection is reduced to 25°, noting the length of wire required to produce the *diminution of* 5°.

The greater the electromotive force, the greater will be the resistance required to effect the diminution of 5°, and the comparative forces of batteries may be expressed by the number of units of resistance employed. (*De la Rive, "Treatise on Electricity,"* vol. ii. p. 788.)

(2.) An approximate measurement may be obtained by placing a few cells, twelve or less, in circuit with a tangent or sine galvanometer, introducing so much resistance, 10,000 units or more, that the resistance of the batteries to be compared may be neglected. The sines or tangents of the deflections obtained will then express the relative electromotive forces. This method, however, is inferior to the former, as it does not admit of the reduction of the measurements to a fixed standard, or of the accurate comparison of measurements taken at different times. Or a condenser may be charged from each battery and discharged through a galvanometer, as in taking a capacity test (432). The electromotive forces will be directly as the deflections observed.

521. *Determination of the joint resistance of two or more circuits between which the current divides, as in the case of a fault, a shunt, or two circuits worked by the same batteries* (219).

When a current splits between two or more conductors, it divides proportionally to their resistances. If the two conductors are precisely alike, it divides equally; if they are similar, save in length, then the current divides between them in the inverse ratio of their lengths.

Let R and r be the resistances of the two circuits, C and c their conductibility; the two united will have a conductibility x equal to C + c, that is, equal to $\frac{1}{R} + \frac{1}{r}$ (resistance being the converse or *reciprocal* of conductibility).

Then the conductibility $x = \frac{1}{R} + \frac{1}{r} = \frac{R+r}{R\,r}$; the resistance being the reciprocal, $\frac{R\,r}{R+r.}$ That is, the resistance of the two circuits, when connected, is equal to the product of their separate resistances divided by their sum.[1]

The joint resistance of any number of conductors, connected side by side or in *multiple arc*, may be found by adding together the *reciprocals* of their respective resistances and finding the reciprocal of the result.

The *reciprocal* of any number is the fraction obtained by dividing unity by that number; and that of any fraction is the fraction itself inverted. Thus the reciprocal of 2 is $\frac{1}{2}$ or ·5; and, conversely, the reciprocal of ·5 or $\frac{1}{2}$ is 2; the reciprocal of $\frac{3}{4}$ is $\frac{4}{3}$.

Let it be required to find the joint resistances of three wires, measuring 20, 30, and 12 ohms respectively.

By the first-named method, the joint resistance of the first two is found thus: $\frac{20 \times 30}{20 + 30} = 12$; and then the resistance of this pair and the third wire $\frac{12 \times 12}{12 + 12} = 6$.

By the second method, the reciprocal of 20 is ·050
30 is ·033
12 is ·083

which added together = ·166,

the reciprocal of which is 6.

This operation is equivalent to the addition of the following fractions, representing the *conductibility* of the several wires, and taking the reciprocal of, or inverting, the fraction representing their sum.—For example, $\frac{1}{20} + \frac{1}{30} + \frac{1}{12} = \frac{1}{6}$, which inverted is $\frac{6}{1}$ or 6.

[1] Gavarret, "Traité d'Électricité," vol. ii. p. 43.

522. FORMULA *for the effective current or strength of signals on a circuit having contact or partial earth* (220):—

Let E be the electromotive force of the battery;

Let R be the resistance of the line from the sending station to the fault, including battery and sending apparatus;

Let r be the resistance of the line beyond the fault, including the receiving apparatus;

Let f be the resistance of the fault;

Then $\frac{Ef}{R(r+f)+rf}$ or $\frac{Ef}{Rr+Rf+rf} = \frac{E}{\frac{Rr}{f}+R+r}$ will equal the received current.

The manner in which this and the following formula are obtained is given in full by Gavarret ("*Traité d'Électricité*," vol. ii. p. 88).

523. FORMULA *for the effective current on a wire having two faults, partial earth, or contact* (224):—

Let E be the electromotive force of the battery;

R the resistance of the wire from the battery to the first fault;

r' that of the line wire between the faults;

r'' that of the wire from the second fault to the distant station, including the apparatus;

L the total circuit $(R + r' + r'')$;

f' the first fault;

f'' the second fault;

The effective current

$$\frac{Ef'f''}{Rf''(R+r'')+r''f'(R+r')+Rr'r''+Lf'f''}$$

Or in the case given in par. 224, p. 117, E being 1000,

$$\frac{1000 \times 20 \times 20}{50 \times 20\,(20+30)+30 \times 20\,(50+20)+50 \times 20 \times 30+100 \times 20 \times 20} = 2{\cdot}4.$$

524. *Effect of temperature on the resistance of iron.*—No. 8 iron wire (·170 in.) increases in resistance between 32° and 60° Fahr.

0·770 ohm per mile, and No. 11 (·125) 1·528 ohms. This is ·2097 per cent. for each degree, and very nearly agrees with Matthiessen's determination for pure iron, ·2180 per cent.

525. *On the graphical solution of problems based on ohms laws.* —Since a current of electricity depends only on resistance and electromotive force, and varies with these two quantities in simple proportion, the one inversely and the other directly ($C = \frac{E}{R}$), we have a very convenient method of representing graphically, by means of geometrical figures, the relations that exist between them.

If we agree that resistances shall be measured along a horizontal line, and electromotive force or potential along a vertical

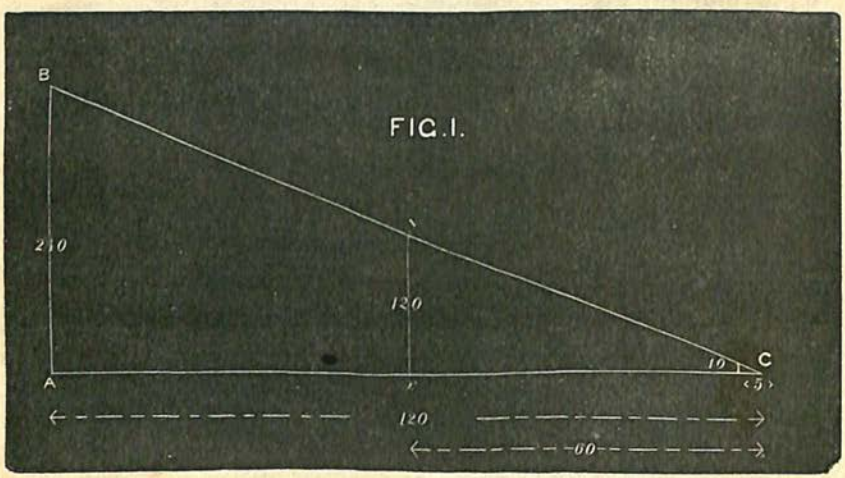

FIG. 115.

line, then the tangent of the angle made by connecting the extremities of these two lines, if they start from a common point, will represent the strength of the current.

The tangent of an angle is, *numerically*, the ratio which the perpendicular of the right-angled triangle, of which it forms part, bears to the base; and *geometrically*, it is represented by the

line cut off between the point where it touches the circle of which one leg is the radius or base, and the other the hypothenuse of the right-angled triangle of which it forms the perpendicular.

Thus $\frac{AB}{AC}$ (Fig. 115) is the numerical, and the line AB the geometrical tangent of the angle ACB when AC is radius.

Let AC represent a resistance of 120 ohms, and AB an electro-motive force of 24 cells, then a line xy at any point of AC will represent the potential at that point. And since the ratios $\frac{AB}{AC}$, $\frac{xy}{Cx}$, and therefore the angle ACB, are everywhere the same, we see that the current is the same at every point of its path at any given moment.

Let AC (Fig. 116) represent the internal resistance of one cell, CD the external resistance of the circuit, AB the electromotive

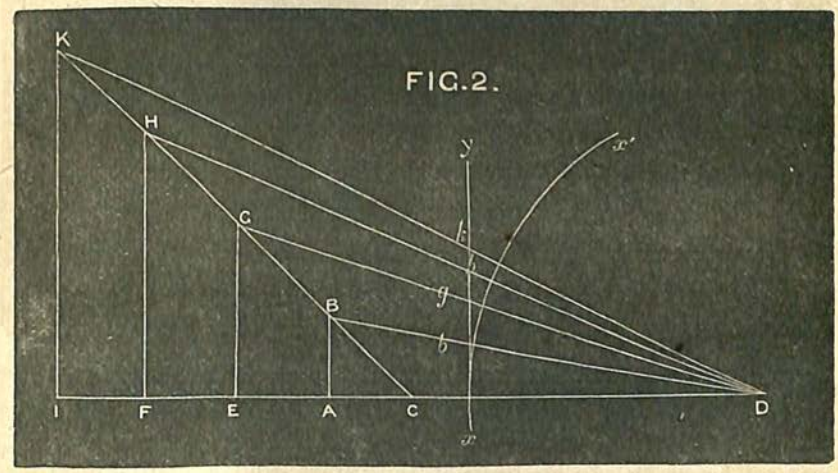

FIG. 116.

force of one cell; then the tangent of the angle BDA represents the current. Add another cell, EC will be the resistance and EG the electromotive force of the two together, and the tan-

gent of the angle E D G will give us the current. Similarly, F C, I C, give the resistances, and F H, I K, the electromotive forces, of three and four cells; the tangents of the angles F D H, I D K, giving the currents. The ratios $\frac{IK}{ID}$, $\frac{FH}{FD}$, $\frac{EG}{ED}$, $\frac{AB}{AD}$, are the numerical tangents in each case; and if we take any length D x as radius and describe the arc xx', drawing the line xy perpendicular to x D, then xb, xg, xh, xk will be the geometrical tangents, the ratios and the lines giving, in each case, the relative strengths of the currents from the different combinations. In this way we see that as we increase the electromotive force, so we increase the current when the external resistance is considerable.

Let now the external resistance be nothing; then the angle A C B will give us the current from one cell, E C G from two cells, F C H from three cells, and I C K from four cells, all these angles being the same. Thus as we add cells we do not disturb the angle F C H, which shows that the circuit from any number of cells on short circuit is the same as that from a single cell.

Thus taking the case of A (par. 87), the diagram Fig. 115 gives precisely the same result as is there worked out numerically. Case B can similarly be solved by Fig. 116. Here L = C D, and E = I K, and R = I C. If the lines xk, xg, xb, be measured, they will be found to be in the proportion 1·0 : ·6 : ·4. In the same way, all the cases given in the subsequent paragraphs can easily be represented and solved graphically. (*Preece.*)

526. *Gaugain's "Tangent Multiplier."*

If a magnetized needle is submitted to the action of a circular current placed in the magnetic meridian, when the centre of the needle occupies the summit of a cone having for its base the circular current, the tangents of the angles of the deviation of the needle will be nearly proportional to the force of the current, when the height of the cone is equal to one-fourth of the diameter of its base. This theorem is correct within $\frac{1}{1300}$, when the

needle is from 1·17 in. to 1·36 in. in length, and the coil (or circular current) not less in diameter than thrice the length of the needle.

The wire of the coil may be wrapped upon the surface of a cone, or section of a cone, fulfilling these conditions, till sufficient

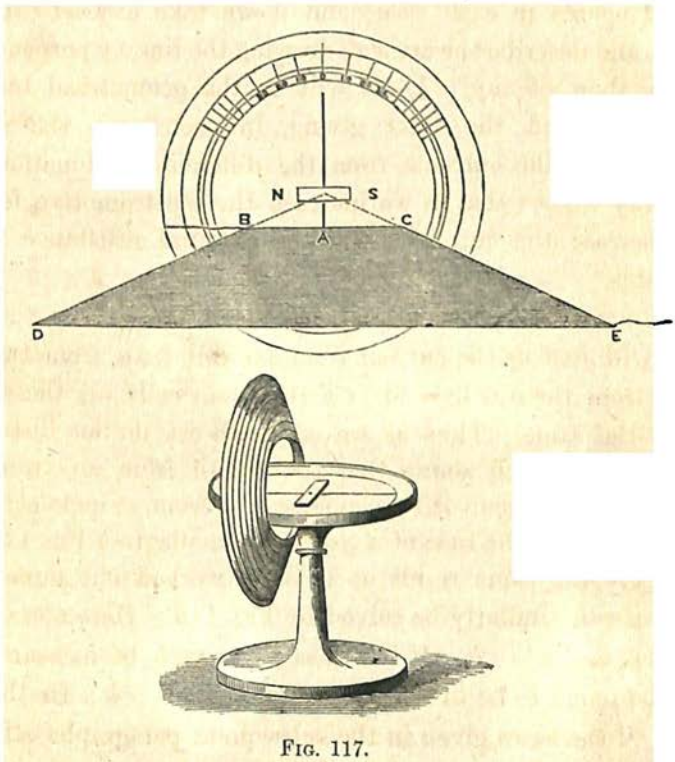

FIG. 117.

breadth is obtained to give the desired sensitiveness. The accuracy of the instrument is not lessened by wrapping several layers of wire one over the other.

When the needle is 1 in. long, the nearest wire, B C, of the circular coil must be placed $\frac{3}{4}$ in. from the centre of the needle N S, and its diameter, B G, must be 3 in.

The angle of the conical coil frame D B C E is found by drawing straight lines from the centre of the needle, through the

points B and C. (See Gavarret, "*Traité d'Electricité*," vol. ii. pp. 54, 55, 56.)

527. *The voltameter.*—When two wires, connected with a battery, are placed a short distance apart in water containing a few drops of sulphuric acid, the water is decomposed. If the wires are terminated by small platinum plates,[1] the oxygen and hydrogen will rise in bubbles through the water; and as the amount of decomposition, and therefore the volume of gas produced, depends upon the quantity of electricity passing in a given time, the volume of gas collected in a graduated glass tube in one minute is an accurate measure of the strength of the current.

FIG. 118.

528. *Preservation of timber.*—The only effectual methods of preserving timber are the chemical processes, and as the price of larch has nearly doubled within the last few years, it has risen so nearly to the cost of chemically prepared inferior timber, such as Scotch fir and Baltic poles, that the chemical method has come largely into use.

If we can expel the fermentable sap from the tree, or by means of an antiseptic prevent its decomposition, we shall prevent the ulterior alteration of the woody fibre itself.

(1.) Kyanising, or steeping the timber in a solution of *bichloride of mercury* or *corrosive sublimate*, has not been extensively tried, because of its expense, and because it does not succeed unless the timber is dry. The poisonous nature of the salt is a very serious objection.

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[1] It is necessary to use platinum, as the oxygen combines with all oxidable metals.

(2.) *Chloride of zinc* has been used both in the same way as mercury, by simple immersion, and as the copper in Boucherie's process. It is said to wash out.

(3.) The following process was tried in Prussia, but without success. Sulphate of iron was injected into the wood, and the excess over and above that which entered into chemical combination with the albumen of the sap, was removed by a subsequent injection of chloride of barium. Iron seems rather to destroy than to preserve wood; it is certainly destructive to oak.

Injection with chloride of calcium, common salt, sulphate of soda, and other salts has been tried without success.

It was thought that if holes were bored 2 or 3 feet into the pole from each end, filled with creosote and securely closed, the creosote would diffuse itself, and thus preserve the timber; this plan, however, has failed. Lateral penetration is very small, especially in heartwood.

529. *Boucherising* (or injection with sulphate of copper) and *creosoting* have been very successful, especially the latter.

The process of creosoting is too well known to need description. The method of boucherising may be described as follows:— A cistern is placed on a scaffold some twenty-four feet above the ground; a tube leads from the cistern to a horizontal pipe, placed about a foot from the ground; from this latter pipe a series of flexible tubes branch out, each having a wooden disc on its end. The poles to be injected are laid on a low trestle, parallel and perpendicular to the main pipe, each butt being opposite a flexible tube; a thin slice is sawn off the butt, a circular india-rubber ring is placed along the edge, the disc attached to the tube is placed on the ring, and screwed tightly against it by the tenon bolts. This plate or disc, together with the ring, forms a water-tight chamber for the reception of the solution of sulphate of copper, communicating with the vertical pressure-pipe. The proportions employed in making the solution are— 1 lb. of sulphate of copper to 5 gallons of water. It is usual

to inject about 0·35 lb. of the sulphate into every cubic foot of timber; this gives a weight of from 1½ lbs. to 2 lbs. of the sulphate for the smallest pole.

It is extremely difficult to inject larch unless it is of very open grain, and very free from resin. No other than quickly grown, soft timber is really suitable. The liquid cannot penetrate the heartwood, and it has sometimes happened in boucherised poles that the heartwood, which is more durable than the sapwood under ordinary circumstances, has rotted, leaving the sapwood sound.

Spruce and Scotch fir are very suitable, and the value of the system is, that by it the cheaper descriptions of fir are rendered more durable than the more expensive sorts when unprepared.

The sulphate of copper must be free from iron. Sulphate of iron is inert, or possibly hurtful; besides this, the iron becomes oxidized by exposure to the air and forms a muddy deposit, which chokes the fine filter formed by the pores at the end of the pole, and thus stops the process.

As the sulphate always contains some iron, it is well to make a saturated solution and allow it to remain exposed to the air as long as possible, so that the iron may deposit at the bottom of the vessel, after which it can be diluted for use. The crystals may be placed in a wicker basket hung at the surface of the water, so that they may dissolve readily.

The solution should be diluted till it contains 1 lb. of the salt to 5 gallons of water. If it be too strong, it appears to contract the sap vessels and to crystallize at their ends.

The water must be free from lime and perfectly clear. If it contains lime, it is as well to add a little sulphuric acid to precipitate it, and either allow it time to settle or filter the water through sand, for even the slightest cloudiness interferes with the injection.

The air must be carefully expelled from the chamber formed

at the butt of the pole. This is best done by inserting a wire between the pole and the packing which forms the side of the chamber. After the tap has been turned to admit the solution, the wire is withdrawn leaving a small hole, and when the water spirts out freely, showing that the air has escaped, this hole can be closed by a blow from a hammer; neglect of this precaution has frequently prevented the injection of the upper side of the entire pole.

As the sap which runs from the trees contains copper, it is allowed to flow into a reservoir, to be used instead of water to form fresh solution. The copper acts as an antiseptic on the putrescible substances in the sap, so that its employment is not injurious.

Although it is quite possible to inject trees which have been cut two or three weeks, the labour will be much more costly than when the work is done quickly, and for the following reasons. It is always necessary to cut a thin slice from the end, however recently the tree may have been felled, because the pores very quickly contract in drying; and if the injecting is not rapidly completed, the pores close, even although they are well wetted by the solution, and however carefully the water has been filtered they become choked by the substances filtered out of the liquid, so that a slice has to be removed from time to time to expose a fresh surface. The apparatus should therefore be erected in the forest itself, so that the trees may be injected the day they are felled. They must not be twisted, crooked or scabby, or the pores will not be sufficiently open.

The process succeeds best in spring and autumn, because the sap is then most fluid and it is not so necessary to be prompt in the preparation; cold hinders it, and frost obviously stops it. It is little use to attempt it in winter. The pressure tank should be elevated about twenty-four feet; if it is too high it is said that the liquid flows too rapidly through the timber to produce its best effect.

It has been found only partially successful for poles to be set in sandy or peaty soil.

Occasiqnally, even in suitable soil, one here and there has decayed rapidly without any apparent cause. This probably arises from the process having been imperfectly performed, for when this is the case the poles will not last as long as well-seasoned unprepared timber, because they have been cut in the summer and set while green.

Zinc and iron decompose sulphate of copper; the bolts and nails used for fixing insulators must therefore be well galvanized, or even tarred over to protect the zinc. This corrosion is especially troublesome in respect to the so-called earth wires or lightning conductors fixed to the poles, which will be corroded and need renewal in a few years; the second set will probably not be affected, because the timber will then be thoroughly dry.

In Belgium, the railway sleepers, which are generally of beech, were at one time boucherised, but it was found that, when they were laid in damp soil, the decomposition of the chairs and spikes replaced the copper by iron, so that the wood became rotten under the chairs while perfectly sound elsewhere.

A comparative trial of boucherised and of unprepared poles was made on the Wilts and Somerset Railway, in 1856. When examined in 1861 all the former were perfectly sound, while of the latter—

20	per cent	of	those set in alluvial soil	were decayed.
21	„	„	in clay	„
21	„	„	in gravel	„
40	„	„	in chalk	„

The Sub-Engineer of the Belgian Telegraph Service states that the probable duration of a boucherised pole in suitable soil is 20 years.

The French employ the process for all their poles. They have

also injected dry timber with sulphate of copper by the vacuum process, but if the vacuum process is used at all it should be employed for creosote.

530. *Creosote.* — Our experience of creosote has not been as great as in the case of copper; but, so far as it has gone, it is in favour of creosote. It does not corrode iron; it does not seem to fail in any soil; and it has another advantage which may seem at first sight a singular one, it repels insects, so that they do not spin their webs in the insulators.

Creosoting can be carried on only at a large depot, and in practice is done by contract. Too low a pressure is sometimes used; water is mixed with the creosote, and the timber is allowed to get wet from exposure before it is placed in the cylinder. It is necessary in all cases to weigh trial poles both before and after the operation, to see that the proper quantity of 8 lbs. per cubic foot has been forced into the timber.

On the other hand, the apparatus for boucherising is inexpensive and portable; the process is readily overlooked, and it is easy to ascertain whether the solution has penetrated the entire pole by testing it with ferrocyanide of potassium, which produces a brown stain with copper.

531. The cost of the sulphate of copper process, calculated on 5,287 Scotch fir poles, injected in the forest, and averaging 25 feet in length, is about twopence per each lineal foot of timber:—

Timber	2·017	pence.
Sulphate of copper	·925	„
Labour, dressing the pole, and wear and tear of apparatus, with a payment of royalty	1·137	„
Total cost	4·079	„

Cost of preparation only . . . . . 2·062 pence.
Cost of an apparatus to prepare 100 poles £110
Strength of solution . . . . . 1 lb. to 5 gallons.
Quantity of solution per lineal foot . . . 1·4 gallons.

The cost of creosoting, calculated on 20,409 poles averaging 25 feet in length of Baltic red pine, is under twopence per each lineal foot of timber :—

Timber	4·336	pence.
Carriage to and from the works . . .	·359	„
Creosoting	1·486	„
Total cost	6·181	„
Cost of preparation only	1·845	„

532. *Morse alphabet.*—The following system may be useful in learning the signals of the Morse and needle instruments :—

The Morse alphabet is formed by dots and dashes : in the needle alphabet the *dot* is represented by a movement to the *left*, the dash by a movement to the right.

The letters whose signals consist of dots or dashes only, are grouped together and represented by a sentence.

Each letter, consisting of dots and dashes combined, is represented by a word or sentence commencing with the letter itself, and made up of long and short syllables corresponding with the dots and dashes of the signal representing it. Thus, the letter D — - - one long and two short, may be represented by the word Dŏmĭnĭe.

THE MORSE CODE.

(1.) Dots	E -	I · ·	S · · ·	H · · · ·
	Earwigs	*infest*	*summer*	*houses.*

(2.) Dashes. T — M — — O — — — CH — — — —

Turnips make oxen cheerful.

(3.) Dots and dashes.

A	- —	ălārm
B	— - - -	beāutĭfŭllў
C	— - — -	cīrcŭmstāntiăl
D	— - -	dōmĭnĭe
F	- - — -	fĭlĭbūstĕr
G	— — -	glāssgrīndĕr
J	- — — —	jăpān vārnīsh
K	— - —	kīss mĕ quīck
L	- — - -	lĕgĭtĭmāte
P	- — — -	prŏnoūnce plāinlў
Q	— — - —	quīck, quēnch thĕ fīre
R	- — -	rĕcēivĕr
U	- - —	ŭnăttāched
V	- - - —	vărĭtў faīr
W	- — —	wĕ lōve plāy
X	— - - —	ēxcĕllĕnt bēer
Y	— - — —	yōu ălārm āll
Z	— — - -	zīnc bāttĕrў.

533. *Cable, artificial.*—In experiments on retardation and on speed of transmission, the effects of induction in cables and buried wires may be obtained by means of one or more condensers of the proper capacity. A cable may be represented by a series of condensers, separated by resistance coils, one set of plates of each condenser being placed in circuit with the resistance coils as a line wire, the other set of plates being connected to earth.

The greater the number of condensers, the more complete the arrangement; as by the insertion of resistance between each one, the inductive effect is more equally distributed throughout the circuit. The total resistance, and also the total capacity, should equal that of the cable to be represented.

By means of such an arrangement, Mr. Varley was able to show the gradual progress of a signal through a cable supposed to have been laid from England to Australia.

TABLES.

TABLE I.

SQUARES AND LOGARITHMS OF NUMBERS FROM 1 TO 1049.

LOGARITHMS are artificial numbers employed to facilitate calculations.

Every logarithm consists of two parts, separated by a decimal point; the latter, or decimal portion, only is given in the tables. The former portion or *index* is, in the case of whole numbers, or whole numbers combined with decimal fractions, one less than the number of figures in the corresponding whole numbers. Thus, the index of the logarithm of 2 will be 0; the index of the logarithm of 20, 1, and so on. These indices must always be supplied.

Multiplication by logarithms.—The sum of the logarithms of two numbers equals the logarithm of their product. Example :—

Multiply 25 by 36. Log. 25 = 1·39794

„ 36 = 1·55630

2·95424 = log. 900.

Division by logarithms.—From the logarithm of the dividend subtract the logarithm of the divisor, the remainder will be the logarithm of the quotient. Example :—

Divide 900 by 36. Log. 900 = 2·95424
„ 36 = 1·55630
1·39794 = log. 25.

Rule of three by logarithms.—Add together the logarithms of the 2nd and 3rd terms, and subtract the logarithm of the 1st term. Example :—

Find a 4th proportional to 36, 25, and 180:

Log. 25 = 1·39794
„ 180 = 2·25527
3·65321
„ 36 = 1·55630
2·09691 = log. 125.

Involution by logarithms.—Multiply the logarithm of the number by the index of the required power. Example :—

Find the cube or 3rd power of 8.

Log. 8 = 0·90309
3
2·70927 = log. 512.

Evolution by logarithms.—Divide the logarithm of the number by the index of the root required. Example :—

Find the cube root or 3rd root of 512.

Log. 512 = 2·70927 ÷ 3 = 0·90309 = log. 8.

From the foregoing examples it will be seen that the addition and subtraction of logarithms give results equivalent to the multiplication and division of their corresponding numbers; while the long and difficult arithmetical operations of raising powers and extracting roots are accomplished by means of simple multiplication and division.

To find the logarithm of a number of four places, from Table I.—Find the logarithm of the first three figures in the table, and take the difference between that logarithm and the next following logarithm. Multiply this difference by the fourth figure of the number, and add one-tenth of the product to the logarithm of the first three figures. Example:—Required the logarithm of 1344. The log. of 134 is 12710, that of 135 is 13033, and the difference 323. Then $\frac{323 \times 4}{10} = 129$, which added to 12710 = 12839. The logarithm of 1344 will, therefore, be 3·12839, when the proper index has been supplied.

The contraction *log.* indicates the common logarithm as given in the table.

Log. $_e$ indicates Napier's system of logarithms; it is sometimes written *log. Nap.*, or *log. nat.* a contraction for *natural* logarithm, or *log. hyp.* for *hyperbolical* logarithm. The logarithms on this system are proportional to the common logs., which may be converted into the Napierian system by being multiplied by 2·3.

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
			50	2500	69897	100	10000	00000
1	1	00000	1	2601	70757	1	10201	00432
2	4	30103	2	2704	71600	2	10404	00860
3	9	47712	3	2809	72427	3	10609	01284
4	16	60206	4	2916	73239	4	10816	01703
5	25	69897	5	3025	74036	5	11025	02119
6	36	77815	6	3136	74819	6	11236	02530
7	49	84510	7	3249	75587	7	11449	02938
8	64	90309	8	3364	76343	8	11664	03342
9	81	95424	9	3481	77085	9	11881	03743
10	100	00000	60	3600	77815	110	12100	04139
1	121	04139	1	3721	78533	1	12321	04532
2	144	07918	2	3844	79239	2	12544	04922
3	169	11394	3	3969	79934	3	12769	05308
4	196	14613	4	4096	80618	4	12996	05690
5	225	17609	5	4225	81291	5	13225	06070
6	256	20412	6	4356	81954	6	13456	06446
7	289	23045	7	4489	82607	7	13689	06818
8	324	25527	8	4624	83251	8	13924	07188
9	361	27875	9	4761	83885	9	14161	07555
20	400	30103	70	4900	84510	120	14400	07918
1	441	32222	1	5041	85126	1	14641	08278
2	484	34242	2	5184	85733	2	14884	08636
3	529	36173	3	5329	86332	3	15129	08990
4	576	38021	4	5476	86923	4	15376	09342
5	625	39794	5	5625	87506	5	15625	09691
6	676	41497	6	5776	88081	6	15876	10037
7	729	43136	7	5929	88649	7	16129	10380
8	784	44716	8	6084	89209	8	16384	10721
9	841	46240	9	6241	89763	9	16641	11059
30	900	47712	80	6400	90309	130	16900	11394
1	961	49136	1	6561	90848	1	17161	11727
2	1024	50515	2	6724	91381	2	17424	12057
3	1089	51851	3	6889	91908	3	17689	12385
4	1156	53148	4	7056	92428	4	17956	12710
5	1225	54407	5	7225	92942	5	18225	13033
6	1296	55630	6	7396	93450	6	18496	13354
7	1369	56820	7	7569	93952	7	18769	13672
8	1444	57978	8	7744	94448	8	19044	13988
9	1521	59106	9	7921	94939	9	19321	14301
40	1600	60206	90	8100	95424	140	19600	14613
1	1681	61278	1	8281	95904	1	19881	14922
2	1764	62325	2	8464	96379	2	20164	15229
3	1849	63347	3	8649	96848	3	20449	15534
4	1936	64345	4	8836	97313	4	20736	15836
5	2025	65321	5	9025	97772	5	21025	16137
6	2116	66276	6	9216	98227	6	21316	16435
7	2209	67210	7	9409	98677	7	21609	16732
8	2304	68124	8	9604	99123	8	21904	17026
9	2401	69020	9	9801	99563	9	22201	17319

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
150	22500	17609	200	40000	30103	250	62500	39794
1	22801	17898	1	40401	30320	1	63001	39967
2	23104	18184	2	40804	30535	2	63504	40140
3	23409	18469	3	41209	30750	3	64009	40312
4	23716	18752	4	41616	30963	4	64516	40483
5	24025	19033	5	42025	31175	5	65025	40654
6	24336	19312	6	42436	31387	6	65536	40824
7	24649	19590	7	42849	31597	7	66049	40993
8	24964	19866	8	43264	31806	8	66564	41162
9	25281	20140	9	43681	32015	9	67081	41330
160	25600	20412	210	44100	32222	260	67600	41497
1	25921	20682	1	44521	32428	1	68121	41664
2	26244	20951	2	44944	32633	2	68644	41830
3	26569	21219	3	45369	32838	3	69169	41995
4	26896	21484	4	45796	33041	4	69696	42160
5	27225	21748	5	46225	33244	5	70225	42324
6	27556	22011	6	46656	33445	6	70756	42488
7	27889	22272	7	47089	33646	7	71289	42651
8	28224	22531	8	47524	33846	8	71824	42813
9	28561	22789	9	47961	34044	9	72361	42975
170	28900	23045	220	48400	34242	270	72900	43136
1	29241	23300	1	48841	34439	1	73441	43297
2	29584	23553	2	49284	34635	2	73984	43457
3	29929	23805	3	49729	34830	3	74529	43616
4	30276	24055	4	50176	35025	4	75076	43775
5	30625	24304	5	50625	35218	5	75625	43933
6	30976	24551	6	51076	35411	6	76176	44091
7	31329	24797	7	51529	35602	7	76729	44248
8	31684	25042	8	51984	35793	8	77284	44404
9	32041	25285	9	52441	35983	9	77841	44560
180	32400	25527	230	52900	36173	280	78400	44716
1	32761	25768	1	53361	36361	1	78961	44871
2	33124	26007	2	53824	36549	2	79524	45025
3	33489	26245	3	54289	36735	3	80089	45179
4	33856	26482	4	54756	36921	4	80656	45332
5	34225	26717	5	55225	37107	5	81225	45484
6	34596	26951	6	55696	37291	6	81796	45637
7	34969	27184	7	56169	37475	7	82369	45788
8	35344	27416	8	56644	37658	8	82944	45939
9	35721	27646	9	57121	37840	9	83521	46090
190	36100	27875	240	57600	38021	290	84100	46240
1	36481	28103	1	58081	38202	1	84681	46389
2	36864	28330	2	58564	38381	2	85264	46538
3	37249	28556	3	59049	38561	3	85849	46687
4	37636	28780	4	59536	38739	4	86436	46835
5	38025	29003	5	60025	38917	5	87025	46982
6	38416	29226	6	60516	39093	6	87616	47129
7	38809	29447	7	61009	39270	7	88209	47276
8	39204	29666	8	61504	39445	8	88804	47422
9	39601	29885	9	62001	39620	9	89401	47567

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
300	90000	47712	350	122500	54407	400	160000	60206
1	90601	47857	1	123201	54531	1	160801	60314
2	91204	48001	2	123904	54654	2	161604	60423
3	91809	48144	3	124609	54777	3	162409	60530
4	92416	48287	4	125316	54900	4	163216	60638
5	93025	48430	5	126025	55023	5	164025	60745
6	93636	48572	6	126736	55145	6	164836	60853
7	94249	48714	7	127449	55267	7	165649	60959
8	94864	48855	8	128164	55388	8	166464	61066
9	95481	48996	9	128881	55509	9	167281	61172
310	96100	49136	360	129600	55680	410	168100	61278
1	96721	49276	1	130321	55751	1	168921	61384
2	97344	49415	2	131044	55871	2	169744	61490
3	97969	49554	3	131769	55991	3	170569	61595
4	98596	49693	4	132496	56110	4	171396	61700
5	99225	49831	5	133225	56229	5	172225	61805
6	99856	49969	6	133956	56348	6	173056	61909
7	100489	50106	7	134689	56467	7	173889	62014
8	101124	50243	8	135424	56585	8	174724	62118
9	101761	50379	9	136161	56703	9	175561	62221
320	102400	50515	370	136900	56820	420	176400	62325
1	103041	50650	1	137641	56937	1	177241	62428
2	103684	50785	2	138384	57054	2	178084	62531
3	104329	50920	3	139129	57171	3	178929	62634
4	104976	51054	4	139876	57287	4	179776	62736
5	105625	51188	5	140625	57403	5	180625	62839
6	106276	51322	6	141376	57519	6	181476	62941
7	106929	51455	7	142129	57634	7	182329	63043
8	107584	51587	8	142884	57749	8	183184	63144
9	108241	51719	9	143641	57864	9	184041	63246
330	108900	51851	380	144400	57978	430	184900	63347
1	109561	51983	1	145161	58092	1	185761	63448
2	110224	52114	2	145924	58206	2	186624	63548
3	110889	52244	3	146689	58320	3	187489	63649
4	111556	52375	4	147456	58433	4	188356	63749
5	112225	52504	5	148225	58546	5	189225	63849
6	112896	52634	6	148996	58659	6	190096	63949
7	113569	52763	7	149769	58771	7	190969	64048
8	114244	52892	8	150544	58883	8	191844	64147
9	114921	53020	9	151321	58995	9	192721	64246
340	115600	53148	390	152100	59106	440	193600	64345
1	116281	53275	1	152881	59218	1	194481	64444
2	116964	53403	2	153664	59329	2	195364	64542
3	117649	53529	3	154449	59439	3	196249	64640
4	118336	53656	4	155236	59550	4	197136	64738
5	119025	53782	5	156025	59660	5	198025	64836
6	119716	53908	6	156816	59769	6	198916	64933
7	120409	54033	7	157609	59879	7	199809	65031
8	121104	54158	8	158404	59988	8	200704	65128
9	121801	54282	9	159201	60097	9	201601	65225

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
450	202500	65321	500	250000	69897	550	302500	74036
1	203401	65418	1	251001	69984	1	303601	74115
2	204304	65514	2	252004	70070	2	304704	74194
3	205209	65610	3	253009	70157	3	305809	74272
4	206116	65705	4	254016	70243	4	306916	74351
5	207025	65801	5	255025	70329	5	308025	74429
6	207936	65896	6	256036	70415	6	309136	74507
7	208849	65992	7	257049	70501	7	310249	74585
8	209764	66086	8	258064	70586	8	311364	74663
9	210681	66181	9	259081	70672	9	312481	74741
460	211600	66276	510	260100	70757	560	313600	74819
1	212521	66370	1	261121	70842	1	314721	74896
2	213444	66464	2	262144	70927	2	315844	74974
3	214369	66558	3	263169	71012	3	316969	75051
4	215296	66652	4	264196	71096	4	318096	75128
5	216225	66745	5	265225	71181	5	319225	75205
6	217156	66838	6	266256	71265	6	320356	75282
7	218089	66932	7	267289	71349	7	321489	75358
8	219024	67024	8	268324	71433	8	322624	75435
9	219961	67117	9	269361	71517	9	323761	75511
470	220900	67210	520	270400	71600	570	324900	75587
1	221841	67302	1	271441	71684	1	326041	75664
2	222784	67394	2	272484	71767	2	327184	75740
3	223729	67486	3	273529	71850	3	328329	75815
4	224676	67578	4	274576	71933	4	329476	75891
5	225625	67669	5	275625	72016	5	330625	75967
6	226576	67761	6	276676	72098	6	331776	76042
7	227529	67852	7	277729	72181	7	332929	76117
8	228484	67943	8	278784	72263	8	334084	76193
9	229441	68033	9	279841	72345	9	335241	76268
480	230400	68124	530	280900	72427	580	336400	76343
1	231361	68214	1	281961	72509	1	337561	76418
2	232324	68305	2	283024	72591	2	338724	76492
3	233289	68395	3	284089	72673	3	339889	76567
4	234256	68484	4	285156	72754	4	341056	76641
5	235225	68574	5	286225	72835	5	342225	76715
6	236196	68664	6	287296	72916	6	343396	76790
7	237169	68753	7	288369	72997	7	344569	76864
8	238144	68842	8	289444	73078	8	345744	76938
9	239121	68931	9	290521	73159	9	346921	77011
490	240100	69020	540	291600	73239	590	348100	77085
1	241081	69108	1	292681	73320	1	349281	77159
2	242064	69196	2	293764	73400	2	350464	77232
3	243049	69285	3	294849	73480	3	351649	77305
4	244036	69373	4	295936	73560	4	352836	77379
5	245025	69460	5	297025	73640	5	354025	77452
6	246016	69548	6	268116	73719	6	355216	77525
7	247009	69636	7	299209	73799	7	356409	77597
8	248004	69723	8	300304	73878	8	357604	77670
9	249001	69810	9	301401	73957	9	358801	77743

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
600	360000	77815	650	422500	81291	700	490000	84510
1	361201	77887	1	423801	81358	1	491401	84572
2	362404	77960	2	425104	81425	2	492804	84634
3	363609	78032	3	426409	81491	3	494209	84695
4	364816	78104	4	427716	81558	4	495616	84757
5	366025	78175	5	429025	81624	5	497025	84819
6	367236	78247	6	430336	81690	6	498436	84880
7	368449	78319	7	431649	81756	7	499849	84942
8	369664	78390	8	432964	81822	8	501264	85003
9	370881	78462	9	434281	81888	9	502681	85065
610	372100	78533	660	435600	81954	710	504100	85126
1	373321	78604	1	436921	82020	1	505521	85187
2	374544	78675	2	438244	82086	2	506944	85248
3	375769	78746	3	439569	82151	3	508369	85309
4	376996	78817	4	440896	82217	4	509796	85370
5	378225	78887	5	442225	82282	5	511225	85431
6	379456	78958	6	443556	82347	6	512656	85491
7	380689	79028	7	444889	82412	7	514089	85552
8	381924	79099	8	446224	82478	8	515524	85612
9	383161	79169	9	447561	82543	9	516961	85673
620	384400	79239	670	448900	82607	720	518400	85733
1	385641	79309	1	450241	82672	1	519841	85793
2	386884	79379	2	451584	82737	2	521284	85854
3	388129	79449	3	452929	82801	3	522729	85914
4	389376	79518	4	454276	82866	4	524176	85974
5	390625	79588	5	455625	82930	5	525625	86034
6	391876	79657	6	456976	82995	6	527076	86094
7	393129	79727	7	458329	83059	7	528529	86153
8	394384	79796	8	459684	83123	8	529984	86213
9	395641	79865	9	461041	83187	9	531441	86273
630	396900	79934	680	462400	83251	730	532900	86332
1	398161	80003	1	463761	83315	1	534361	86392
2	399424	80072	2	465124	83378	2	535824	86451
3	400689	80140	3	466489	83442	3	537289	86510
4	401956	80209	4	467856	83506	4	538756	86570
5	403225	80277	5	469225	83569	5	540225	86629
6	404496	80346	6	470596	83632	6	541696	86688
7	405769	80414	7	471969	83696	7	543169	86747
8	407044	80482	8	473344	83759	8	544644	86806
9	408321	80550	9	474721	83822	9	546121	86864
640	409600	80618	690	476100	83885	740	547600	86923
1	410881	80686	1	477481	83948	1	549081	86982
2	412164	80753	2	478864	84011	2	550564	87040
3	413449	80821	3	480249	84073	3	552049	87099
4	414736	80888	4	481636	84136	4	553536	87157
5	416025	80956	5	483025	84198	5	555025	87216
6	417316	81023	6	484416	84261	6	556516	87274
7	418609	81090	7	485809	84323	7	558009	87332
8	419904	81157	8	487204	84385	8	559504	87390
9	421201	81224	9	488601	84448	9	561001	87448

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
750	562500	87506	800	640000	90309	850	722500	92942
1	564001	87564	1	641601	90363	1	724201	92993
2	565504	87622	2	643204	90417	2	725904	93044
3	567009	87679	3	644809	90471	3	727609	93095
4	568516	87737	4	646416	90526	4	729316	93146
5	570025	87795	5	648025	90579	5	731025	93197
6	571536	87852	6	649636	90633	6	732736	93247
7	573049	87909	7	651249	90687	7	734449	93298
8	574564	87967	8	652864	90741	8	736164	93349
9	576081	88024	9	654481	90795	9	737881	93399
760	577600	88081	810	656100	90848	860	739600	93450
1	579121	88138	1	657721	90902	1	741321	93500
2	580644	88195	2	659344	90956	2	743044	93551
3	582169	88252	3	660969	91009	3	744769	93601
4	583696	88309	4	662596	91062	4	746496	93651
5	585225	88366	5	664225	91116	5	748225	93702
6	586756	88423	6	665856	91169	6	749956	93752
7	588289	88479	7	667489	91222	7	751689	93802
8	589824	88536	8	669124	91275	8	753424	93852
9	591361	88593	9	670761	91328	9	755161	93902
770	592900	88649	820	672400	91381	870	756900	93952
1	594441	88705	1	674041	91434	1	758641	94002
2	595984	88762	2	675684	91487	2	760384	94052
3	597529	88818	3	677329	91540	3	762129	94101
4	599076	88874	4	678976	91593	4	763876	94151
5	600625	88930	5	680625	91645	5	765625	94201
6	602176	88986	6	682276	91698	6	767376	94250
7	603729	89042	7	683929	91750	7	769129	94300
8	605284	89098	8	685584	91803	8	770884	94349
9	606841	89154	9	687241	91855	9	772641	94399
780	608400	89209	830	688900	91908	880	774400	94448
1	609961	89265	1	690561	91960	1	776161	94497
2	611524	89321	2	692224	92012	2	777924	94547
3	613089	89376	3	693889	92064	3	779689	94596
4	614656	89432	4	695556	92117	4	781456	94645
5	616225	89487	5	697225	92169	5	783225	94694
6	617796	89542	6	698896	92221	6	784996	94743
7	619369	89597	7	700569	92272	7	786769	94792
8	620944	89653	8	702244	92324	8	788544	94841
9	622521	89708	9	703921	92376	9	790321	94890
790	624100	89763	840	705600	92428	890	792100	94939
1	625681	89818	1	707281	92479	1	793881	94988
2	627264	89872	2	708964	92531	2	795664	95036
3	628849	89927	3	710649	92583	3	797449	95085
4	630436	89982	4	712336	92634	4	799236	95134
5	632025	90037	5	714025	92686	5	801025	95182
6	633616	90091	6	715716	92737	6	802816	95231
7	635209	90146	7	717409	92788	7	804609	95279
8	636804	90200	8	719104	92839	8	806404	95328
9	638401	90255	9	720801	92891	9	808201	95376

TABLE I.

SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
900	810000	95424	950	902500	97772	1000	1000000	00000
1	811801	95472	1	904401	97818	1	1002001	00043
2	813604	95521	2	906304	97864	2	1004004	00087
3	815409	95569	3	908209	97909	3	1006009	00130
4	817216	95617	4	910116	97955	4	1008016	00173
5	819025	95665	5	912025	98000	5	1010025	00217
6	820836	95713	6	913936	98046	6	1012036	00260
7	822649	95761	7	915849	98091	7	1014049	00303
8	824464	95808	8	917764	98136	8	1016064	00346
9	826281	95856	9	919681	98182	9	1018081	00389
910	828100	95904	960	921600	98227	1010	1020100	00432
1	829921	95952	1	923521	98272	1	1022121	00475
2	831744	95999	2	925444	98317	2	1024144	00518
3	833569	96047	3	927369	98363	3	1026169	00561
4	835396	96095	4	929296	98408	4	1028196	00604
5	837225	96142	5	931225	98453	5	1030225	00647
6	839056	96189	6	933156	98498	6	1032256	00689
7	840889	96237	7	935089	98543	7	1034289	00732
8	842724	96284	8	937024	98587	8	1036324	00775
9	844561	96331	9	938961	98632	9	1038361	00817
920	846400	96379	970	940900	98677	1020	1040400	00860
1	848241	96426	1	942841	98722	1	1042441	00902
2	850084	96473	2	944784	98767	2	1044484	00945
3	851929	96520	3	946729	98811	3	1046529	00987
4	853776	96567	4	948676	98856	4	1048576	01030
5	855625	96614	5	950625	98900	5	1050625	01072
6	857476	96661	6	952576	98945	6	1052676	01115
7	859329	96708	7	954529	98989	7	1054729	01157
8	861184	96755	8	956484	99034	8	1056784	01199
9	863041	96801	9	958441	99078	9	1058841	01241
930	864900	96848	980	960400	99123	1030	1060900	01284
1	866761	96895	1	962361	99167	1	1062961	01326
2	868624	96941	2	964324	99211	2	1065024	01368
3	870489	96988	3	966289	99255	3	1067089	01410
4	872356	97035	4	968256	99299	4	1069156	01452
5	874225	97081	5	970225	99344	5	1071225	01494
6	876096	97127	6	972196	99388	6	1073296	01536
7	877969	97174	7	974169	99432	7	1075369	01578
8	879844	97220	8	976144	99476	8	1077444	01620
9	881721	97266	9	978121	99520	9	1079521	01661
940	883600	97313	990	980100	99563	1040	1081600	01703
1	885481	97359	1	982081	99607	1	1083681	01745
2	887364	97405	2	984064	99651	2	1085764	01787
3	889249	97451	3	986049	99695	3	1087849	01828
4	891136	97497	4	988036	99739	4	1089936	01870
5	893025	97543	5	990025	99782	5	1092025	01912
6	894916	97589	6	992016	99826	6	1094116	01953
7	896809	97635	7	994009	99869	7	1096209	01995
8	898704	97681	8	996004	99913	8	1098304	02036
9	900601	97727	9	998001	99956	9	1100401	02077

TABLE II.

NATURAL SINES AND TANGENTS.

Deg.	Sine.	Tangent.	Deg.	Sine.	Tangent.	Deg.	Sine.	Tangent.
1	·017	·017	31	·515	·601	61	·874	1·80
2	·035	·035	32	·530	·625	62	·883	1·88
3	·052	·052	33	·544	·649	63	·891	1 96
4	·070	·070	34	·559	·674	64	·899	2·05
5	·087	·087	35	·573	·700	65	·906	2·14
6	·104	·105	36	·588	·726	66	·913	2·24
7	·122	·123	37	·602	·753	67	·920	2·35
8	·139	·140	38	·615	·781	68	·927	2·47
9	·156	·158	39	·629	·810	69	·933	2·60
10	·173	·176	40	·643	·839	70	·939	2·75
11	·191	·194	41	·656	·869	71	·945	2·90
12	·208	·212	42	·669	·900	72	·951	3·08
13	·225	·231	43	·682	·932	73	·956	3·27
14	·242	·249	44	·694	·965	74	·961	3·49
15	·259	·268	45	·707	1·000	75	·966	3·73
16	·275	·287	46	·719	1·03	76	·970	4·01
17	·292	·306	47	·731	1·07	77	·974	4·33
18	·309	·325	48	·743	1·11	78	·978	4·70
19	·325	·344	49	·755	1·15	79	·981	5·14
20	·342	·364	50	·766	1·19	80	·985	5·67
21	·358	·384	51	·777	1·23	81	·987	6·31
22	·374	·404	52	·788	1·28	82	·990	7·11
23	·391	·424	53	·798	1·33	83	·992	8·14
24	·407	·445	54	·809	1·37	84	·994	9·51
25	·422	·466	55	·819	1·43	85	·996	11·43
26	·438	·488	56	·829	1·48	86	·997	14·30
27	·454	·509	57	·838	1·54	87	·998	19·08
28	·469	·532	58	·848	1·60	88	·999	28·63
29	·485	·554	59	·857	1·66	89	·999	57·29
30	·500	·577	60	·866	1·73	90	1·000	Infinite.

(HUTTON'S *Tables.*)

TABLE III.

FOR THE CONVERSION OF DEGREES OF THE CENTIGRADE THERMOMETER INTO THOSE OF FAHRENHEIT.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32·0	14	57·2	28	82·4
1	33·8	15	59·0	29	84·2
2	35·6	16	60·8	30	86·0
3	37·4	17	62·6	31	87·8
4	39·2	18	64·4	32	89·6
5	41·0	19	66·2	33	91·4
6	42·8	20	68·0	34	93·2
7	44·6	21	69·8	35	95·0
8	46·4	22	71·6	36	96·8
9	48·2	23	73·4	37	98·6
10	50·0	24	75·2	38	100·4
11	51·8	25	77·0	39	102·2
12	53·6	26	78·8	40	104·0
13	55·4	27	80·6	41	105·8

(MILLER'S *Chemistry.*)

TABLE IV.

FRENCH WEIGHTS AND MEASURES.

Millimetres.	Inches.	Millimetres.	Inches.	Millimetres.	Inches.
1	0·039	45	1·771	125	4·941
2	0·078	50	1·968	130	5·118
3	0·118	55	2·165	135	5·315
4	0·157	60	2·362	140	5·512
5	0·197	65	2·559	145	5·708
6	0·236	70	2·756	150	5·906
7	0·275	75	2·953	155	6·103
8	0·315	80	3·149	160	6·299
9	0·354	85	3·346	165	6·496
10	0·394	90	3·543	170	6·693
15	0·590	95	3·740	175	6·890
20	0·787	100	3·937	180	7·087
25	0·984	105	4·134	185	7·284
30	1·181	110	4·331	190	7·480
35	1·378	115	4·528	195	7·677
40	1·575	120	4·744	200	7·874

1 inch = 25·4 millimetres.

	Inches.	Feet.	Yards.
1 Millimetre . .	0·039	—	—
1 Centimetre . .	0·393	—	—
1 Decimetre . .	3·937	—	—
1 Metre	39·370	3·280	1·093
1 Kilometre . .	39,370·790	3,280·899	1,093·633

Miles . . .	1	2	3	4	5	6	7	8	9
Kilometres .	1·609	3·219	4 828	6·437	8·047	9·656	11·265	12·874	14·484

	Grains Troy.	Pounds Avoirdupois.
1 Milligramme	0·015	...
1 Centigramme	0·154	...
1 Decigramme	1·543	...
1 Gramme	15·432	...
1 Kilogramme	15,432·348	2·2046
2 ,, ...	...	4·4092
3 ,, ...	...	6·6138
4 ,, ...	...	8·8184
5 ,, ...	...	11·0230
6 ,, ...	...	13·2276
7 ,, ...	...	15·4322
8 ,, ...	...	17·6368
9 ,, ...	...	19·8414

7,000 grains Troy = 1 pound Avoidupois.
1 Litre = 35·275 fluid ounces = 1·764 pints = 61·024 cubic inches.
1 cubic centimetre = ·0610 cubic inches.

TABLE V.

MILES, CHAINS, YARDS, AND FEET.

Miles.	Chns.	Yds.	Feet.
·125 . . .	10	220	660
·25 . . .	20	440	1320
·50 . . .	40	880	2640
·75 . . .	60	1320	3960
1·00 . . .	80	1760	5280
2·00 . . .	160	3520	10560
3·00 . . .	240	5280	15840

Miles.	Chns.	Yds.	Feet.
4·00 . . .	320	7040	21120
5·00 . . .	400	8800	26400
6·00 . . .	480	10560	31680
7·00 . . .	560	12320	36960
8·00 . . .	640	14080	42240
9·00 . . .	720	15840	47520
10·00 . . .	800	17600	52800

Yds.		Chs.	Yds.
50	equal	2	6
100	,,	4	12
150	,,	6	18
200	,,	9	2
250	,,	11	8
300	,,	13	14
350	,,	15	20
400	,,	18	4
450	,,	20	10
500	,,	22	16
550	,,	25	0
600	,,	27	6

Yds.		Chs.	Yds.
650	equal	29	12
700	,,	31	18
750	,,	34	2
800	,,	36	8
850	,,	38	14
900	,,	40	20
950	,,	43	4
1000	,,	45	10
1050	,,	47	16
1100	,,	50	0
1150	,,	52	6
1200	,,	54	12

Yds.		Chs.	Yds.
1250	equal	56	18
1300	,,	59	2
1350	,,	61	8
1400	,,	63	14
1450	,,	65	20
1500	,,	68	4
1550	,,	70	10
1600	,,	72	16
1650	,,	75	0
1700	,,	77	6
1750	,,	79	12

Chs.		Yds.
1	equal	22
2	,,	44
3	,,	66
4	,,	88
5	,,	110
6	,,	132
7	,,	154
8	,,	176
9	,,	198
10	,,	220
11	,,	242
12	,,	264
13	,,	286
14	,,	308
15	,,	330
16	,,	352
17	,,	374
18	,,	396
19	,,	418
20	,,	440

¼ mile.

Chs.		Yds.
21	equal	462
22	,,	484
23	,,	506
24	,,	528
25	,,	550
26	,,	572
27	,,	594
28	,,	616
29	,,	638
30	,,	660
31	,,	682
32	,,	704
33	,,	726
34	,,	748
35	,,	770
36	,,	792
37	,,	814
38	,,	836
39	,,	858
40	,,	880

½ mile.

Chs.		Yds.
41	equal	902
42	,,	924
43	,,	946
44	,,	968
45	,,	990
46	,,	1012
47	,,	1034
48	,,	1056
49	,,	1078
50	,,	1100
51	,,	1122
52	,,	1144
53	,,	1166
54	,,	1188
55	,,	1210
56	,,	1232
57	,,	1254
58	,,	1276
57	,,	1298
60	,,	1320

¾ mile.

Chs.		Yds.
61	equal	1342
62	,,	1364
63	,,	1386
64	,,	1408
65	,,	1430
66	,,	1452
67	,,	1474
68	,,	1496
69	,,	1518
70	,,	1540
71	,,	1562
72	,,	1584
73	,,	1606
74	,,	1628
75	,,	1650
76	,,	1672
77	,,	1694
78	,,	1716
79	,,	1738
80	,,	1760

1 mile.

1 Statute Mile . . . . . = 1760 yards, or 5280 feet.
1 Nautical Mile (knot or naut) = 2027$\frac{2}{3}$,, ,, 6083 ,,
1 Admiralty Knot . . . . . = 2026$\frac{2}{3}$,, ,, 6080 ,,
1 Telegraph Knot. . . . . = 2020 ,, ,, 6087 ,,

TABLE VI.

KNOTS AND STATUTE MILES.

Kts.	Miles.	Kts.	Miles.	Kts.	Miles.	Kts.	Miles.	Kts.	Miles.
1	1·1528	21	24·2096	41	47·2664	61	70·3232	81	93·3800
2	2·3057	2	25·3625	2	48·4193	2	71·4761	2	94·5329
3	3·4585	3	26·5153	3	49·5721	3	72·6289	3	95·6857
4	4·6114	4	27·6682	4	50·7250	4	73·7818	4	96·8386
5	5·7642	5	28·8210	5	51·8778	5	74·9346	5	97·9914
6	6·9170	6	29·9738	6	53·0306	6	76·0874	6	99·1442
7	8·0699	7	31·1267	7	54·1835	7	77·2403	7	100·2971
8	9·2127	8	32·2795	8	55·3363	8	78·3931	8	101·4499
9	10·3756	9	33·4324	9	56·4892	9	79·5460	9	102·6028
10	11·5284	30	34·5852	50	57·6420	70	80·6988	90	103·7556
1	12·6812	1	35·7380	1	58·7948	1	81·8516	1	104·9084
2	13·8341	2	36·8909	2	59·9477	2	83·0045	2	106·0613
3	14·9869	3	38·0437	3	61·1005	3	84·1573	3	107·2141
4	16·1398	4	39·1966	4	62·2534	4	85·3102	4	108·3670
5	17·2926	5	40·3494	5	63·4062	5	86·4630	5	109·5198
6	18·4454	6	41·5022	6	64·5590	6	87·6158	6	110·6726
7	19·5983	7	42·6551	7	65·7119	7	88·7687	7	111·8255
8	20·7511	8	43·8079	8	66·8647	8	89·9215	8	112·9783
9	21·9040	9	44·9608	9	68·0176	9	91·0744	9	114·1312
20	23·0568	40	46·1136	60	69·1704	80	92·2272	100	115·2840

STATUTE MILES AND KNOTS.

Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.
1	0·8674	21	18·2158	41	35·5643	61	52·9128	81	70·2612
2	1·7348	2	19·0833	2	36·4318	2	53·7802	2	71·1286
3	2·6023	3	19·9507	3	37·2992	3	54·6476	3	71·9960
4	3·4697	4	20·8181	4	38·1666	4	55·5150	4	72·8635
5	4·3371	5	21·6856	5	39·0340	5	56·3825	5	73·7309
6	5·2045	6	22·5530	6	39·9014	6	57·2499	6	74·5983
7	6·0719	7	23·4204	7	40·7689	7	58·1173	7	75·4657
8	6·9394	8	24·2878	8	41·6363	8	58·9847	8	76·3332
9	7·8068	9	25·1552	9	42·5037	9	59·8521	9	77·2006
10	8·6742	30	26·0227	50	43·3711	70	60·7196	90	78·0680
1	9·5416	1	26·8901	1	44·2386	1	61·5870	1	78·9354
2	10·4091	2	27·7575	2	45·1060	2	62·4544	2	79·8028
3	11·2765	3	28·6249	3	45·9734	3	63·3218	3	80·6703
4	12·1439	4	29·4924	4	46·8408	4	64·1892	4	81·5377
5	13·0113	5	30·3598	5	47·7082	5	65·0567	5	82·4051
6	13·8787	6	31·2272	6	48·5757	6	65·9241	6	83·2725
7	14·7462	7	32·0946	7	49·4431	7	66·7915	7	84·1400
8	15·6136	8	32·9620	8	50·3105	8	67·6590	8	85·0074
9	16·4810	9	33·8295	9	51·1779	9	68·5264	9	85·8748
20	17·3484	40	34·6969	60	52·0453	80	69·3938	100	86·7422

TABLE VII.

APPROXIMATE CUBICAL CONTENTS OF ROUND TELEGRAPH POLES.

Length.	MEAN DIAMETERS IN INCHES.																
	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾	8	8¼	8½	8¾	9
	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.	cub. ft.
18 feet	2·45	2·70	2·96	3·24	3·53	3·83	4·14	4·47	4·81	5·16	5·52	5·89	6·28	6·68	7·09	7·51	7·95
20 „	2·72	3·00	3·29	3·60	3·92	4·25	4·60	4·97	5·34	5·73	6·13	6·55	6·98	7·42	7·88	8·35	8·83
22 „	2·99	3·30	3·62	3·96	4·31	4·68	5·07	5·46	5·87	6·30	6·74	7·20	7·67	8·16	8·66	9·18	9·71
24 „	3·27	3·60	3·95	4·32	4·71	5·11	5·53	5·96	6·41	6·88	7·36	7·86	8·37	8·90	9·45	10·02	10·60
26 „	3·54	3·90	4·28	4·68	5·11	5·53	5·99	6·46	6·94	7·45	7·97	8·51	9·07	9·65	10·24	10·85	11·48
28 „	3·81	4·20	4·62	5·04	5·49	5·96	6·45	6·95	7·48	8·02	8·58	9·17	9·77	10·39	11·03	11·69	12·37
30 „	4·09	4·50	4·94	5·40	5·88	6·38	6·91	7·45	8·01	8·60	9·20	9·82	10·47	11·13	11·82	12·52	13·25
32 „	4·36	4·81	5·27	5·77	6·28	6·81	7·37	7·95	8·55	9·17	9·81	10·48	11·17	11·87	12·61	13·36	14·13
34 „	4·63	5·11	5·60	6·13	6·67	7·24	7·83	8·44	9·08	9·74	10·43	11·13	11·86	12·62	13·39	14·19	15·02
36 „	4·90	5·41	5·93	6·49	7·06	7·66	8·29	8·94	9·62	10·32	11·04	11·79	12·56	13·36	14·18	15·03	15·90
38 „	5·18	5·71	6·26	6·85	7·46	8·09	8·75	9·44	10·15	10·89	11·65	12·44	13·26	14·10	14·97	15·86	16·78
40 „	5·45	6·01	6·59	7·21	7·85	8·52	9·21	9·94	10·69	11·40	12·27	13·10	13·96	14·84	15·76	16·70	17·67
42 „	5·72	6·31	6·92	7·57	8·24	8·94	9·67	10·43	11·22	12·03	12·88	13·75	14·65	15·59	16·54	17·53	18·56
44 „	6·00	6·61	7·25	7·93	8·64	9·38	10·15	10·93	11·76	12·61	13·50	14·40	15·36	16·34	17·34	18·37	19·44
46 „	6·26	6·90	7·57	8·28	9·01	9·78	10·58	11·59	12·27	13·16	14·09	15·04	16·03	17·05	18·13	19·18	20·29
48 „	6·54	7·21	7·91	8·65	9·42	10·22	11·06	11·92	12·82	13·76	14·72	15·72	16·75	17·81	18·91	20·04	21·20
50 „	6·81	7·51	8·25	9·01	9·81	10·65	11·52	12·42	13·35	14·33	15·33	16·37	17·44	18·54	19·70	20·87	22·08

TABLE VIII.

SHOWING THE STRAIN CORRESPONDING TO THE *SAG* OR DIP OF A WIRE SUSPENDED AT BOTH ENDS.

Sag in Inches.	No. 8 Wire (ordinary), 88 yards span.	No. 8 Wire (ordinary), 110 yards' span.	No. 11 Wire (homogeneous), 110 yards' span.	No. 11 Wire (ordinary), 110 yards' span.
	lbs.	lbs.	lbs.	lbs.
24	**313**	429	266	**224**
23	326	**448**	**280**	235
22	**340**	467	291	246
21	359	486	302	257
20	**377**	**504**	313	268
19	397	532	324	**280**
18	**418**	**560**	**336**	294
17	448	588	355	308
16	**477**	**616**	374	322
15	510	...	**392**	**336**
14	**543**	...	420	355
13	583	...	**448**	374
12	**624**	...	476	**392**
11	690	...	**504**	420
10	**756**	...	...	**448**
9	841	...	...	476
8	**926**	...	...	**504**
7	**1,018**	...	...	...

The larger figures are the results of actual observation, the smaller are filled in from calculation. The differences from the theoretical values are caused by the stiffness of the wire, which prevents it taking the true curve. The table may be useful as showing that relation between sag and strain which is likely to be met with in practice.

TABLE IX.

IRON AND COPPER WIRE.

IRON WIRE.

Birmingham Wire Gauge.	Diameter.		Area of Section.	Weight of 100 yards.	Weight of 1 mile.	Length of 1 cwt.	Breaking Strain.	
							Hard Wire.	Soft Wire.
	Inches.	Millimetres.	Sq. in.	Lbs.	Lbs.	Yards.	Lbs.	Lbs.
00	0·363	9·21	0·103	102·00	1794	110	8600	6000
0	0·331	8·40	0·086	84·72	1490	132	7100	4750
1	0·300	7·61	0·071	68·75	1210	162	6000	4000
2	0·280	7·11	0·062	59·90	1054	187	4850	3400
3	0·260	6·60	0·053	51·65	909	215	4000	2900
4	0·240	6·10	0·045	44·00	775	255	3400	2500
5	0·220	5·59	0·038	37·00	651	303	2950	2200
6	0·200	5·08	0·031	30·56	538	361	2500	1800
7	0·185	4·69	0·0265	26·15	461	428	2200	1520
8	0·170	4·31	0·023	22·10	389	509	1750	1200
9	0·155	3·93	0·0195	18·36	323	609	1500	950
10	0·140	3·55	0·016	14·97	264	747	1200	820
11	0·125	3·17	0·0125	11·95	211	939	820	650
12	0·110	2·79	0·010	9·24	163	1244	710	510
13	0·095	2·41	0·0071	7·05	124	1589	640	400
14	0·085	2·15	0·0057	5·51	97	2031	510	350
15	0·075	1·92	0·0044	4·29	76	2608	410	300
16	0·065	1·65	0·0033	3·22	57	3473	350	200
17	0·057	1·44	0·0026	2·48	44	4515	280	150
18	0·050	1·27	0·0020	1·91	34	5600	200	115
19	0·045	1·14	0·0016	1·55	27	7246	150	85
20	0·040	1·01	0·0013	1·22	21	9168	110	65
21	0·035	0·88	0·0010	0·94	17	11980	85	50
22	0·030	0·76	0·0007	0·69	12	16300	65	40

The above table has been supplied by Messrs. Johnson and Nephew, of Manchester; the *soft* wire is that manufactured by them expressly for telegraphic purposes.

Birmingham Wire Gauge.—The diameters of the several gauges must be considered approximate only. There is no authorized standard, and the sizes of different makers vary considerably.

TABLE IX.—(*continued*).

COPPER WIRE. (*Hall.*)

Birmingham Wire Gauge (Approximate).	Diameter.		Number of yards in 1 pound.	Weight in lbs. of 1 mile (1760 yards).	Resistance of 1 mile of pure Copper at 32° Fahr.	Approximate weight of Silk required to cover a pound of Wire singly.
	Inches.	Millimetres.				Oz.
4½	·2302	5·847	2·095	840·09	1·00	
5	·226	5·740	2·175	809·20	1·038	
6	·198	5·029	2·834	621·00	1·352	
7	·183	4·648	3·317	530·59	1·583	
8	·175	4·445	3·628	485·10	1·731	
9	·160	4·064	3·350	404·60	2·068	
10	·136	3·454	6·007	292·99	2·867	
11	·128	3·251	6·781	259·55	3·237	
12	·107	2·717	9·705	181·35	4·623	
13	·10	2·54	11·11	158·41	5·300	
...	·092	2·336	13·125	134·40	6·266	
14½	·08	2·032	17·36	101·39	8·288	
15½	·07	1·778	22·67	77·63	10·82	
16	·065	1·651	26·29	66·96	12·25	
...	·0625	1·587	28·472	61·81	13·59	
...	·06	1·521	30·864	57·02	14·73	
17	·058	1·473	33·03	53·29	15·76	
...	·056	1·422	35·432	49·67	16·91	
...	·054	1·371	38·104	46·19	18·18	
...	·052	1·32	41·091	42·83	19·61	
18	·05	1·274	44·444	39·60	21·21	½
...	·048	1·219	48·225	36·50	23·02	
...	·046	1·168	52·51	33·52	25·06	
19	·044	1·117	57·39	30·67	27·39	
...	·042	1·066	62·98	27·94	30·06	
20	·04	1·016	69·444	25·34	33·14	
...	·038	·965	77·16	22·81	36·72	
21	·036	·914	85·766	20·52	40·92	
...	·034	·864	95·29	18·47	45·48	
...	·032	·813	108·5	16·22	51·79	¾
22	·03	·762	123·46	14·26	58·93	
...	·028	·711	141·72	12·42	67·65	
23½	·026	·660	164·36	10·71	78·46	
24½	·024	·609	192·9	9·12	92·08	
25	·022	·558	229·56	7·61	109·58	1
26	·02	·508	277·78	6·33	132·59	

TABLE IX.—(*continued*).

COPPER WIRE.

Birmingham Wire Gauge (Approximate).	Diameter.		Number of yards in 1 pound.	Weight in lbs. of 1 mile (1760 yards).	Resistance of 1 mile of pure Copper at 32° Fahr.	Approximate weight of Silk required to cover a pound of Wire singly.
	Inches.	Millimetres.				oz.
27	·018	·457	342·94	5·13	163·69	
28	·016	·406	434·03	4·05	207·17	1
30	·014	·355	569·51	3·09	270·58	
31	·012	·305	771·60	2·28	368·30	
32	·01	·254	1111·11	1·58	530·35	
34	·0095	·241	1231·10	1·43	587·64	1½
...	·009	·228	1371·7	1·28	654·75	
35	·0085	·216	1537·8	1·14	734·05	
36	·008	·203	1736·1	1·01	828·67	
...	·0075	·190	1975·3	0·8910	942·84	2
...	·007	·177	2267·6	0·7761	1082·4	
37	·0065	·165	2629·9	0·6692	1225·3	
38	·006	·152	3086·4	0·5702	1473·1	
...	·0055	·139	3673·1	0·4791	1753·2	2½
...	·005	·127	4444·4	0·3960	2121·4	
39	·0045	·114	5487·0	0·3207	2619·0	
40	·004	·106	6944·4	0·2534	3314·7	
...	·0035	·088	9070·3	0·1945	4329·4	
41	·003	·076	12346·0	0·1425	5892·7	
...	·0025	·063	17777·0	0·099	8485·6	

To find the percentage of Conductivity in a sample of wire, pure copper being taken as = 100 :—

Divide the resistance of 1 mile of pure copper wire of the same size (column 6), by the actual resistance of 1 mile of the wire tested (reduced to 32° Fahr.), and multiply by 100.

TABLE X.

AMERICAN WIRE GAUGE.

No. of Gauge.	Size of each No.	Weight of Wire, per 1000 Lineal Feet.			
		Wrought Iron.	Steel.	Copper.	Brass.
	Inch.	Lbs.	Lbs.	Lbs.	Lbs.
0000	·46000	560·74	566·03	640·51	605·18
000	·40964	444·68	448·88	507·95	479·91
00	·36480	352·66	355·99	402·83	380·67
0	·32486	279·67	282·30	319·45	301·82
1	·28930	221·79	223·89	253·34	239·35
2	·25763	175·89	177·55	200·91	189·82
3	·22942	139·48	140·80	159·32	150·52
4	·20431	110·62	111·66	126·35	119·38
5	·18194	87·720	88·548	100·20	94·666
6	·16202	69·565	70·221	79·462	75·075
7	·14428	55·165	55·685	63·013	59·545
8	·12849	43·751	44·164	49·976	47·219
9	·11443	34·699	35·026	39·636	37·437
10	·10189	27·512	27·772	31·426	29·687
11	·090742	21·820	22·026	24·924	23·549
12	·080808	17·304	17·468	19·766	18·676
13	·071961	13·722	13·851	15·674	14·809
14	·064084	10·886	10·989	12·435	11·746
15	·057068	8·631	8·712	9·859	9·315
16	·050820	6·845	6·909	7·819	7·587
17	·045257	5·427	5·478	6·199	5·857
18	·040303	4·304	4·344	4·916	4·645
19	·035890	3·413	3·445	3·899	3·684
20	·031961	2·708	2·734	3·094	2·920
21	·028462	2·147	2·167	2·452	2·317
22	·025347	1·703	1·719	1·945	1·838
23	·022571	1·350	1·363	1·542	1·457
24	·020100	1·071	1·081	1·223	1·155
25	·017900	0·8491	0·8571	·9699	0·9163
26	·015940	0·6734	0·6797	·7692	0·7267
27	·014195	0·5340	0·5391	·6099	0·5763
28	·012641	0·4235	0·4275	·4837	0·4570
29	·011257	0·3358	0·3389	·3835	0·3624
30	·010025	0·2663	0·2688	·3042	0·2874
31	·008928	0·2113	0·2132	·2413	0·2280
32	·007950	0·1675	0·1691	·1913	·1808
33	·007080	0·1328	0·1341	·1517	·1434
34	·006304	0·1053	0·1063	·1204	·1137
35	·005614	·08366	·08445	·0956	·09015
36	·005000	·06625	·06687	·0757	·0715
37	·004453	·05255	·05304	·06003	·05671
38	·003965	·04166	·04205	·04758	·04496
39	·003531	·03305	·03336	·03775	·03566
40	·003144	·02620	·02644	·02992	·02827
Specific Gravity		7·7747	7·847	8·880	8·386
Weight per Cubic Foot		485·874	90·45	554·988	524·16

(*From* Nystrom's *Pocket-book.*)

TABLE XI.

RESISTANCES IN OHMS OF METALS AND ALLOYS AT 0° CENTIGRADE (32° FAHRENHEIT).

METALS AND ALLOYS.	Relative Resistances, Silver = 1.	Resistance of a wire one foot long, weighing one grain.	Resistance of a wire one foot long, 1-1000th inch in diameter.	Approximate percentage of variation in resistance per degree of temperature at 20° C.
Silver annealed	1·00	0·2214	9·936	0·377
„ hard drawn . . .	0·92	0·2421	9·151	...
Copper annealed	0·98	0·2064	9·718	0·388
„ hard drawn . . .	1·00	0·2106	9·940	...
Gold, annealed	1·26	0·5849	12·52	0·365
„ hard drawn . . .	1·28	0·5950	12·74	...
Brass	4·50	...	...	...
Platinum, annealed . . .	5·54	3·536	55·09	...
Iron, annealed	5·95	1·2425	59·10	...
Tin, pressed	8·09	1·317	80·36	0·365
Lead, pressed	12·02	3·236	119·39	0·387
German Silver, hard or annealed	12·81	2·652	127·32	0·044
Platinum Silver alloy, hard or annealed (two parts Platinum, one part Silver)	14·93	4·243	148·35	0·031
Mercury, liquid	60·38	18·740	600·0	0·072

Let it be required to know the resistance at 0° of a conductor of pure *hard* copper, weighing 400 lbs. per knot. This is equivalent to 460 grains per foot. The resistance of a wire weighing one grain per foot is 0·2106 ; therefore, the resistance of a foot of wire weighing 460 grains will be $\frac{0\cdot2106}{460}$, but the resistance of one knot will be 6,087 times that of one foot, hence the resistance required will be $\frac{6087 \times 0\cdot2106}{460} = 2\cdot79$ units. If the diameter of the wire be given, instead of its weight per knot, the constant for English measures would be taken from the fourth column of the table. Thus the resistance at 0° of a knot of pure hard drawn copper wire 0·1 in. diameter would be $\frac{6087 \times 9\cdot94}{100^2} = 6\cdot05$.

(JENKIN—*Cantor Lectures.*)

TABLE XII.

RESISTANCE IN OHMS OF WIRES ONE FOOT LONG WEIGHING ONE GRAIN, AT VARIOUS TEMPERATURES.

(*Jenkin.*)

Temperature.		Soft Copper.	Hard Copper.	German Silver.	Platinum Silver.
Fahrenheit.	Centigrade.				
32	0	0·2064	0·2106	2·652	4·24
41	5	0·2102	0·2147	2·657	4·25
50	10	0·2144	0·2188	2·661	4·25
51·8	11	0·2153	0·2197	...	...
53·6	12	0·2161	0·2205	...	...
55·4	13	0·2170	0·2214	...	...
57·2	14	0·2178	0·2222	...	...
59·0	15	0·2186	0·2231	2·666	4·26
60·8	16	0·2194	0·2239	...	...
62·6	17	0·2203	0·2248	...	..
64·4	18	0·2211	0·2256	...	...
66·2	19	0·2220	0·2265	...	...
68·0	20	0·2228	0·2272	2·670	4·27
69·8	21	0·2237	0·2283	...	...
71·6	22	0·2242	0·2288	...	...
73·4	23	0·2253	0·2299	...	...
75·2	24	0·2262	0·2308	...	...
77·0	25	0·2271	0·2317	2·675	4·27
78·8	26	0·2279	0·2325	...	...
80·6	27	0·2287	0·2334	...	...
82·4	28	0·2296	0·2343	...	...
84·2	29	0·2305	0·2352	...	...
86·0	30	0·2313	0·2360	2·680	4·28
87·8	31	0·2322	0·2369	...	...
89·6	32	0·2328	0·2375	...	...
91·4	33	0·2340	0·2388	...	...
93·2	34	0·2348	0·2396	...	...
95·0	35	0·2357	0·2405	2·684	4·28
96·8	36	0·2365	0·2413	...	...
98·6	37	0·2376	0·2424	...	...
100·4	38	0·2383	0·2432	...	...
102·2	39	0·2391	0·2440	...	...
104·0	40	0·2400	0·2449	2·689	4·29

At zero Cent.—

1 foot-grain Platinum, annealed = 3·536 ohms.
1 „ Silver, hard = 0·2421 „
By weight 1 Platinum = 14·6 Silver.
1 foot ·001 inch in diameter Platinum = 55·09 „
1 „ „ Silver = 9·151 „
By volume 1 Platinum = 6·009 Silver.

The resistance of German Silver varies with its composition. A sample tested by Mr. Becker showed a resistance of 3·644 ohms at 58° Fahr. for a foot-grain.

TABLE XIII.

CO-EFFICIENTS FOR THE REDUCTION OF THE RESISTANCE OF COPPER WIRES OF VARYING CONDUCTIVITY TO ANY OTHER TEMPERATURE.

CO-EFFICIENTS FOR THE REDUCTION TO A HIGHER TEMPERATURE.

(*G. E. P.*)

Difference of Temperature.	Pure Copper.		96 per Cent.		94 per Cent.		92 per Cent.	
Degrees Fahr.	Co-efficient.	Log.	Co-efficient.	Log.	Co-efficient.	Log.	Co-efficient.	Log.
0	1·00000	0·0000000	1·0000	0·0000000	1·00000	0·00000000	1·0000	0·0000000
1	1·00206	·0008950	1·0020	·0008592	1·00194	·0008418	1·00190	·0008234
2	1·00413	·0017900	1·0040	·0017184	1·0039	·0016826	1·0038	·0016468
3	1·00620	·002685	1·00595	·0025776	1·0058	·0025239	1·0057	·0024702
4	1·00828	·003580	1·00795	·0034368	1·0078	·0033652	1·0076	·0032936
5	1·01036	·004475	1·00995	·0042960	1·0097	·0042065	1·0095	·0041170
6	1·01244	·005370	1·01195	·0051552	1·0117	·0050478	1·01145	·0049404
7	1·01453	·006265	1·01395	·0060144	1·01635	·0058891	1·01335	·0057638
8	1·01662	·007160	1·01595	·0068736	1·0156	·0067304	1·0153	·0065872
9	1·01872	·008055	1·0180	·0077328	1·0176	·0075717	1·0172	·0074106
10	1·02082	·008950	1·0199	·0085920	1·0196	·0084130	1·01915	·0082340
11	1·02293	·009845	1·0220	·0094512	1·0215	·0092543	1·0211	·0090574
12	1·02504	·010740	1·0240	·0103104	1·0235	·0100956	1·0230	·0098808
13	1·02715	·011635	1·02605	·0111696	1·0255	·0109369	1·02495	·0107042
14	1·02927	·012530	1·0281	·0120288	1·0275	·0117782	1·0269	·0115276
15	1·03139	·013425	1·0301	·0128880	1·0295	·0126195	1·02885	·0123510
16	1·03352	·014320	1·03215	·0137472	1·0315	·0134608	1·030	·0131744
17	1·03565	·015215	1·0342	·0146064	1·0335	·0143021	1·03275	·0139978
18	1·03779	·016110	1·03625	·0154656	1·0355	·0151434	1·0347	·0148212
19	1·03993	·017005	1·0383	·0163248	1·0375	·0159847	1·0367	·0156446
20	1·04208	·017900	1·04035	·0171840	1·0395	·0168260	1·03865	·0164680
21	1·04423	·018795	1·0424	·0180432	1·0415	·0176673	1·0406	·0172914
22	1·04638	·019690	1·0445	·0189024	1·0435	·0185086	1·0426	·0181148
23	1·04854	·020585	1·04655	·0197616	1·0456	·0193499	1·0446	·0189382
24	1·05070	·021480	1·0486	·0206208	1·0476	·0201912	1·04655	·0197616
25	1·05287	·022375	1·0507	·0214800	1·0496	·0210325	1·04855	·0205850
26	1·05504	·023270	1·0528	·0223392	1·05165	·0218738	1·0505	·0214084
27	1·05722	·024165	1·0549	·0231984	1·0537	·0227151	1·0525	·0222318
28	1·05940	·025060	1·05695	·0240576	1·0557	·0235564	1·0545	·0230552
29	1·06158	·025955	1·05905	·0249168	1·0578	·0243977	1·0565	·0238786
30	1·06377	·026850	1·06115	·0257760	1·0598	·0252390	1·0585	·0247020

To reduce the resistance of a Copper Wire of a specified conductivity from the observed temperature to a higher.—Under the column corresponding to the specified conductivity, and opposite the number of degrees answering to the difference between the observed and the required temperature, will be found the co-efficient; multiply the observed resistance by this co-efficient, and the product is the resistance required.

For reducing to a lower temperature proceed in the same manner, but obtain the co-efficient from the second table.

TABLE XIII.—(*continued*).

CO-EFFICIENTS FOR THE REDUCTION TO A LOWER TEMPERATURE.

(*G. E. P.*)

Difference of Temperature.	Pure Copper.		96 per Cent.		94 per Cent.		92 per Cent.	
Degrees Fahr.	Co-efficient.	Log.	Co-efficient.	Log.	Co-efficient.	Log.	Co-efficient.	Log.
0	1·00000	0·0000000	1·00000	0·0000000	1·00000	0·0000000	1·00000	0·0000000
1	0·99794	$\bar{1}$·9991050	0·99802	$\bar{1}$·9991408	0·998065	$\bar{1}$·9991587	0·998105	$\bar{1}$·9991766
2	0·99588	·9982100	0·99605	·9982816	0·99613	·9983174	0·996215	·9983532
3	0·99383	·9973150	0·99408	·9974224	0·994205	·9974761	0·99433	·9975298
4	0·99179	·9964200	0·99212	·9965632	0·99228	·9966348	0·992445	·9967064
5	0·98975	·9955250	0·99016	·9957040	0·99036	·9957935	0·990565	·9958830
6	0·98771	·9946300	0·98820	·9948448	0·988445	·9949522	0·98869	·9950596
7	0·98567	·9937350	0·98625	·9939856	0·98653	·9941109	0·98682	·9942362
8	0·98365	·9928400	0·98430	·9931264	0·98462	·9932696	0·98494	·9934128
9	0·98162	·9919450	0·98235	·9922672	0·98272	·9924283	0·98308	·9925894
10	0·97960	·9910500	0·98041	·9914080	0·980815	·9915870	0·98122	·9917660
11	0·97758	·9901550	0·97847	·9905488	0·978915	·9907457	0·97936	·9909426
12	0·97557	·9892600	0·97654	·9896896	0·97702	·9899044	0·97751	·9901192
13	0·97356	·9883650	0·97461	9888304	0·97513	·9890631	0·97565	·9892958
14	0·97156	·9874700	0·97268	·9879712	0·973245	·9882218	0·978805	·9884724
15	0·96956	·9865750	0·97076	·9871120	0·97136	·9873805	0·97196	·9876490
16	0·96756	·9856800	0·96884	·9862528	0·96948	·9865392	0·97012	·9868256
17	0·96557	·9847850	0·96693	·9853936	0·967605	·9856979	0·96828	·9860022
18	0·96358	·9838900	0·96502	·9845344	0·96578	·9848566	0·96645	·9851788
19	0·96160	·9829950	0·96311	·9836752	0·96386	·9840153	0·96462	·9843554
20	0·95962	·9821000	0·961205	·9828160	0·96200	·9831740	0·96279	·9835320
21	0·95764	·9812050	0·959305	·9819568	0·96014	·9823327	0·96097	·9827086
22	0·95567	·9803100	0·96741	·9810976	0·95828	·9814914	0·95915	·9818852
23	0·95370	·9794150	0·95552	·9802384	0·95642	·9806501	0·95733	·9810618
24	0·95174	·9785200	0·95363	·9793792	0·95457	·9798088	0·95552	·9802384
25	0·94978	·9776250	0·95174	·9785200	0·952725	·9789675	0·95371	·9794150
26	0·94783	·9767300	0·94986	·9776608	0·95088	·9781262	0·95190	·9785916
27	0·94587	·9758350	0·947985	·9768016	0·94904	·9772849	0·95010	·9777682
28	0·94393	·9749400	0·94611	·9759424	0·947205	·9764436	0·94830	·9769448
29	0·94198	·9740450	0·94424	·9750832	0·94537	·9756023	0·94650	·9761214
30	0·94004	·9731500	0·942375	·9742240	0·94354	·9747610	0·94471	·9752980

To reduce the resistance of a Copper Wire of a specified conductivity from the observed temperature to a higher.—Under the column corresponding to the specified conductivity and opposite the number of degrees answering to the difference between the observed and the required temperature, will be found the co-efficient; multiply the observed resistance by this co-efficient, and the product is the resistance required.

For reducing to a lower temperature proceed in the same manner, but obtain the co-efficient from the second table.

TABLE XIV.

RESISTANCE OF A KNOT-POUND OF PURE COPPER AT VARYING TEMPERATURES.

Degrees.	Resistance.	Degrees.	Resistance.
75° Fahr.	1192·33 Ohm.	53° Fahr.	1139·48 Ohm.
74	1189·87	52	1137·18
73	1187·42	51	1134·79
72	1184·98	50	1132·45
71	1182·54	49	1130·12
70	1180·10	48	1127·80
69	1177·67	47	1125·48
68	1175·25	46	1123·16
67	1172·83	45	1120·85
66	1170·42	44	1118·54
65	1168·01	43	1116·24
64	1165·60	42	1113·94
63	1163·20	41	1111·64
62	1160·81	40	1109·35
61	1158·42	39	1107·07
60	1156·03	38	1104·79
59	1153·65	37	1102·52
58	1151·28	36	1100·25
57	1148·91	35	1097·98
56	1146·54	34	1095·72
55	1144·18	33	1093·47
54	1141·83	32	1091·22

TABLE XV.

INFLUENCE OF TEMPERATURE ON INSULATING MATERIAL.

Table of Co-efficients for the reduction of the observed insulation resistance of a core a any temperature to that at 75° Fahr.

(*G. E. P.*)

Temp. Fahr.	Ordinary Percha.		Willoughby Smith's Improved Percha.		Hooper's Insulator.		Temp. Fahr.
	Co-efficient.	Logarithm.	Co-efficient.	Logarithm.	Co-efficient.	Logarithm.	
32°	23·622	1·3733167	27·913	1·4458065	3·016	0·4794313	32°
33	21·947	·3413752	25·834	·4121917	2·940	·4683473	33
34	20·391	·3094385	23·910	·3785796	2·865	·4571246	34
35	18·945	·2774946	22·128	·3449422	2·796	·4465372	35
36	17·602	·2455620	20·480	·3113300	2·722	·4348881	36
37	16·354	·2136240	18·954	·2777009	2·653	·4237372	37
38	15·195	·1817007	17·542	·2440791	2·586	·4126285	38
39	14·117	·1497424	16·235	·2104523	2·520	·4014005	39
40	13·116	·1178014	15·025	·1768145	2·456	·3902284	40
41	12·186	·0858612	13·906	·1432022	2·394	·3791241	41
42	11·322	·0539232	12·870	·1095785	2·333	·3679147	42
43	10·520	·0220157	11·911	·0759482	2·274	·3567905	43
44	9·774	0·9900723	11·024	·0423392	2·216	·3455698	44
45	9·081	·9581337	10·203	·0087279	2·160	·3344533	45
46	8·437	·9261880	9·442	0·9750640	2·105	·3232521	46
47	7·839	·8942607	8·739	·9414617	2·052	·3121774	47
48	7·283	·8623103	8·088	·9078411	2·000	·3010300	48
49	6·767	·8303962	7·485	·8741918	1·949	·2898118	49
50	6·287	·7984435	6·928	·8406079	1·900	·2787536	50
51	5·841	·7664872	6·412	·8069935	1·852	·2676410	51
52	5·427	·7345598	5·934	·7733475	1·805	·2564772	52
53	5·042	·7026028	5·492	·7397305	1·759	·2452658	53
54	4·685	·6707096	5·083	·7061201	1·715	·2342641	54
55	4·353	·6387887	4·704	·6724673	1·671	·2229764	55
56	4·044	·6068111	4·354	·6388884	1·629	·2119211	56
57	3·757	·5748412	4·029	·6051973	1·587	·2005769	57
58	3·491	·5429498	3·729	·5715924	1·547	·1894903	58
59	3·244	·5110808	3·451	·5379450	1·508	·1784013	59
60	3·013	·4789991	3·194	·5043349	1·470	·1673173	60
61	2·800	·4471580	2·956	·4707044	1·433	·1562462	61
62	2·601	·4151404	2·736	·4371161	1·396	·1448354	62
63	2·417	·3832767	2·532	·4034637	1·361	·1338581	63
64	2·245	·3512163	2·343	·3697723	1·326	·1225485	64
65	2·086	·3193143	2·169	·3362596	1·293	·1115985	65
66	1·938	·2873538	2·007	·3025474	1·260	·1003705	66
67	1·801	·2555137	1·858	·2690457	1·228	·0891984	67
68	1·673	·2234959	1·719	·2352759	1·197	·0780942	68
69	1·555	·1917304	1·591	·2016702	1·167	·0670709	69
70	1·444	·1595672	1·473	·1682027	1·137	·0557605	70
71	1·342	·1277525	1·363	·1344959	1·108	·0445393	71
72	1·247	·0958665	1·261	·1007151	1·080	·0334238	72
73	1·158	·0637086	1·167	·0670709	1·053	·0224284	73
74	1·076	·0318123	1·080	·0334238	1·026	·0111474	74
75	1·000	·0000000	1·000	·0000000	1·000	·0000000	75
76	·9418	1·9739587	·9375	1·9719713	·9746	1·9888264	76
77	·8870	·9479236	·8789	·9439395	·9500	·9777236	77
78	·8354	·9218945	·8240	·9159272	·9259	·9665641	78
79	·7867	·8958092	·7725	·8878985	·9034	·9558801	79

TABLE XV.—(*continued*).

INFLUENCE OF TEMPERATURE ON INSULATING MATERIAL.

Temp. Fahr.	Ordinary Percha.		Willoughby Smith's Improved Percha.		Hooper's Insulator.		Temp. Fahr.
	Co-efficient.	Logarithm.	Co-efficient	Logarithm.	Co-efficient.	Logarithm.	
80°	·7410	·8698182	·7242	·8598585	·8795	·9442358	80°
81	·6978	·8437310	·6789	·8318058	·8572	·9330822	81
82	·6572	·8176976	·6365	·8037984	·8355	·9219465	82
83	·6190	·7916906	·5967	·7757560	·8144	·9108378	83
84	·5829	·7655941	·5594	·7477225	·7937	·8996564	84
85	·5490	·7395723	·5245	·7197455	·7736	·8885165	85
86	·5171	·7135745	·4917	·6917002	·7540	·8773713	86
87	·4870	·6875290	·4609	·6636067	·7349	·8662282	87
88	·4586	·6614341	·4321	·6355843	·7162	·8550343	88
89	·4319	·6353832	·4051	·6075622	·6981	·8439176	89
90	·4068	·6093809	·3798	·5795550	·6804	·8327643	90
91	·3831	·5833122	·3561	·5515720	·6631	·8215790	91
92	·3608	·5572665	·3338	·5234863	·6463	·8104342	92
93	·3398	·5312234	·3130	·4955443	·6299	·7992716	93
94	·3200	·5051500	·2934	·4674601	·6140	·7881684	94
95	·3014	·4791432	·2751	·4394906	·5984	·7769916	95
96	·2839	·4531654	·2579	·4114513	·5832	·7658175	96
97	·2674	·4271614	·2417	·3832767	·5541	·7435882	97
98	·2518	·4010557	·2266	·3552599	·5400	·7323938	98
99	·2371	·3749316	·2125	·3273589	·5263	·7212334	99
100	·2233	·3488887	·1992	·2992893	·5130	·7101174	100

To find the resistance at a given temperature from an observed resistance at another temperature:—

As the co-efficient of the observed temperature is to the co-efficient of the required temperature, so is the observed resistance to the resistance required.

Where the resistance required is at 75° Fahr., it will be sufficient to divide the observed resistance by the co-efficient corresponding to the observed temperature in the table.

The resistances of percha are as given by Mr. Willoughby Smith; those of Hooper's Insulator are as given by Mr. Warren, in Clark and Sabine's "Electrical Tables."

The improvement effected by Mr. Willoughby Smith has reduced the electrostatic capacity about twenty per cent., without in any way injuring the mechanical or chemical properties.

TABLE XVI.

RESISTANCE (COMPARATIVE) OF ORDINARY AND WILLOUGHBY SMITH'S GUTTA-PERCHA, AND HOOPER'S MATERIAL, AT DIFFERENT TEMPERATURES, SHOWING THE DECREASE OF RESISTANCE DUE TO THE INCREASE OF TEMPERATURE.

(*G. E. P.*)

Temperature.	Ordinary Gutta-Percha.	Willoughby Smith's Gutta-Percha.	Hooper's Material.
32°	100·00	100·00	100·00
35	80·20	79·27	92·71
40	55·52	53·83	81·43
45	38·44	36·55	71·62
50	26·62	24·82	63·00
55	18·43	16·85	55·40
60	12·76	11·44	48·74
65	8·83	7·77	42·87
70	6·11	5·28	37·70
75	4·23	3·58	33·16
80	3·14	2·59	29·16
85	2·32	1·88	27·67
90	1·72	1·36	23·62
95	1·28	0·98	19·84
100	·94	0·71	17·01

The data for Gutta-percha are from Mr. Willoughby Smith's tables; those for Hooper's Material from Mr. Warren's table, as given in Clark and Sabine.

TABLE XVII.

WEIGHTS OF COPPER AND GUTTA-PERCHA.

SILVERTOWN TABLE. PER NAUT, 2,029 YARDS.

Gauge.	Diameter.	Copper.	Gutta-Percha (solid).
		Lbs.	Lbs.
No. 1	·310	1773·4	192·7
2	·280	1434·7	155·9
3	·260	1246·5	135·4
4	·240	1058·4	115·0
5	·220	893·7	97·0
6	·200	729·1	79·2
7	·187	635·0	69·0
8	·166	493·9	53·6
9	·158	446·8	48·5
10	·137	329·2	35·7
11	·125	282·2	30·6
12	·109	211·6	23·0
13	·095	164·6	17·8
14	·083	117·6	12·7
15	·072	94·0	10·2
16	·065	70·5	7·6
17	·056	47·0	5·1
18	·049	42·3	4·6
19	·042	30·5	3·3
20	·035	21·1	2·3

This table has been furnished by the Silvertown Gutta-Percha Works. It will be observed that the diameters of the gauges vary from those given in Table IX., and that the specific gravity of the copper differs also.

To find the weight of the percha of a core of given diameter, deduct the weight of a cylinder of percha equal in diameter to the conductor from the tabular weight of solid gutta-percha.

GUTTA-PERCHA COMPANY'S TABLE.

Gauge.	Diameter.	Weight per Stat. Mile. Gutta-Percha (solid).	Weight per Naut. Mile. Gutta Percha (solid).
		Lbs.	Lbs.
00	·126	28	32
0	·143	36	41
8	·161	46	53
7	·171	52	59
6	·194	66	77
5	·214	81	93
4	·221	86	99
3	·247	108	124
2	·276	134	155
1	·289	147	170
0	·340	204	235
00	·380	255	294
000	·425	319	368
0000	·454	364	420
½-inch	·500	442	509

This table has been furnished by Mr. Chatterton, of the Gutta-Percha Company, Wharf Road.

The weight and diameter of No. 7 gauge, the size used for underground wires in towns, are, approximately—

Outside diameter . . . . . ·171 inch.
Weight of Copper per statute mile . . . 39 lbs.
,, Percha ,, ,, . . . 46 ,,

TABLE XVIII.

MECHANICAL AND ELECTRICAL DATA OF VARIOUS RECENT SUBMARINE TELEGRAPH CABLES.

	Cable.	Date.	Length laid.	Weight per Knot.						Diameter.			Resistance of Conductor at 24° Cent.		Resistance of Dielectric at 24° Cent.		Electro-static Capacity.		Remarks.
				Copper.	Gutta Percha.	Iron.	Hemp.	Asphalt.	Complete.	Copper, d.	Core, D.	Logarithm of $\frac{D}{d}$ (approx.).	Resistance per knot.	Specific Conductivity, Pure Copper = 100.	Resistance per knot.	Specific Resistance.	Electro-static Capacity per knot.	Specific Inductive Capacity.	
			Knots.	Lbs.	Lbs.	Tons.	Tons.	Tons.	Tons.	Mils.	Mils.		Ohms.		Megohms.	Megohms.	Microfarads.	Microfarads.	
1	Persian Gulf	1864	1148	225	275	3·060	—	—	3·73	110	380	·53781	6·25	84·79	190	1002	0·3486	·0661	
2	Atlantic	1865	1896	300	400	0·632	·8055	none.	1·75	147	467	·52763	4·27	93·09	349	1805	0·3535	·0684	
3	Persian Gulf	1866	160	225	275	3·060	—	—	3·73	110	380	·53781	6·01	88·17	395	2084	0·3312	·0628	
4	Atlantic	1866	1852	300	400	0·632	·8055	none.	1·75	147	467	·52763	4·20	94·63	342	1768	0·3535	·0684	
5	England and Hanover	1866	224	107	150	17·065 8·100	·3396	·637	18·49 10·94	87	280	·53655	12·07	92·32	239	1213	0·3447	·0679	Shore-ends. Main Cable.
6	Placentia Bay and Sydney	1867	112·1 188·7	150	230	2·150	·2210	none.	2·54	102	348	·55266	8·96	88·71	455	2237	0·3566	·0725	Placentia and St. Pierre. St. Pierre and Sydney.
7	Cuba and Florida	1867																	
	Havannah to Key West		125·4	107	166	2·100	·2782	none.	2·50	87	290	·55750	12·38	90·02	464	2270	0·3507	·0717	
	Key West to Pimta Rassa		119·9																
8	Anglo-Mediterranean	1868	927	150	200	—	—	—	—	103	327	·52763	8·73	91·05	496	2565	0·4500	·0870	
9	French Atlantic	1869																	
	Brest—St. Pierre		2584	400	400	17·795	·2170	2·113	20·477										Shore-ends.
	" "		—	"	"	4·605	·3680	·921	6·246	168	470	·47129	3·16	94·33	235	1361	0·4295	·0742	Intermediate.
	" "		—	"	"	·709	1·040	·487	1·652										Main Cable.
	St. Pierre—Duxbury		749	107	150	14·972	·1090	1·563	16·760										Shore-ends.
	" "		—	"	"	4·753	·5280	·879	6·276	87	282	·53655	12·03	92·63	266	1350	0·3740	·0737	Intermediate.
	" "		—	"	"	1·949	·1095	·700	2·875										Main Cable.
10	British Indian	1870																	
	Suez—Aden		1460·66	120	175	9·758	·5400	·927	11·412										Shore-ends.
	" "		—	"	"	2·725	·1310	·330	3·286	92	304	·54530	10·42	95·35	329	1646	0·3580	·0716	Intermediate.
	" "		—	"	"	1·193	·1890	·459	2·712										Main Cable.
	Aden—Bombay		1817·43	180	240	9·759	·7250	1·080	11·737										Shore-ends (Aden).
	" "		—	"	"	11·705	·1460	·698	12·737										" (Bombay).
	" "		—	"	"	5·429	·3250	·691	6·633	113	358	·52763	7·02	94·36	278	1441	0·3610	·0696	Intermediate (No. 1).
	" "		—	"	"	2·851	·0830	·345	3·414										" (No. 2).
	" "		—	"	"	1·186	·1460	·352	1·872										Main.

TABLE XVIII.—(*continued*).

MECHANICAL AND ELECTRICAL DATA OF VARIOUS RECENT SUBMARINE TELEGRAPH CABLES.

	Cable.	Date.	Length laid.	Weight per Knot.						Diameter.			Resistance of Conductor at 24° Cent.		Resistance of Dielectric at 24° Cent.		Electro-static Capacity.		Remarks.
				Copper.	Gutta Percha.	Iron.	Hemp.	Asphalt.	Complete.	Copper, *d*.	Core, *D*.	Logarithm of $\frac{D}{d}$ (approx.).	Resistance per knot.	Specific Conductivity, Pure Copper = 100.	Resistance per knot.	Specific Resistance.	Electro-static Capacity per knot.	Specific Inductive Capacity.	
			Knots.	Lbs.	Lbs.	Tons.	Tons.	Tons.	Tons.	Mils.	Mils.		Ohms.		Meg-ohms.	Meg-ohms.	Micro-farads.	Micro-farads.	
11	Falmouth—Gibraltar	1870																	
	Falmouth—Lisbon		27·75	120	175	10·604	·7250	1·080	11·737										Shore-ends.
	,, ,,		144·80	,,	,,	3·018	·0900	·350	3·420										Intermediate (No. 1).
	,, ,,		651·06	,,	,,	·709	·1040	·487	1·652										Main Cable (No. 1).
	Lisbon—Gibraltar		12·00	120	175	10·604	·7250	1·080	11·737	92	304	·54530	10·508	94·55	214	1070	0·3645	·0729	Shore-ends.
	,, ,,		15·00	,,	,,	3·018	·0900	·350	3·420										Intermediate (No. 1).
	,, ,,		274·00	,,	,,	·923	·0630	·244	1·535										Main Cable (No. 2).
	,, ,,		45·00	,,	,,	5·917	·3250	·691	6·633										Intermediate (No. 2).
12	Gibraltar—Malta	1870	4·00	120	175	10·604	·7250	1·080	11·737										
	,, ,,		251·97	,,	,,	3·018	·0900	·350	3·420										Shore-ends.
	,, ,,		846·29	,,	,,	·923	·0630	·244	1·535	92	304	·54530	10·508	94·55	214	1070	0·3480	·0696	Intermediate (No. 1).
	,, ,,		2·81	,,	,,	5·917	·3250	·691	6·633										Main Cable (No. 2).
13	Marseilles, Algiers, & Malta	1870																	Intermediate (No. 2).
	Marseilles—Bona		16	107	166	10·604	·7250	1·080	11·737										[Core.
	,, ,,		486	,,	,,	1·054	·1400	·346	1·864	87	272	·50242	12·03	92·62	273	1482	0·286	·0527	Shore-ends. Willoughby Smith's
	Bona—Malta		24	107	166	10·604	·7250	1·080	11·737										Main Cable ,, ,,
	,, ,,		336	,,	,,	1·211	·1500	·360	1·880	87	272	·50242	12·17	91·57	238	1291	0·286	·0527	Shore-ends ,, ,,
14	Anglo-Mediterranean Duplicate	1870	906	107	140	·923	·0650	·244	1·535	—	—	—	—	—	—	—	—	—	Main Cable ,, ,,
15	British Indian Extension	1871		,,	,,	,,	,,	,,	,,										Lengths of various Cables ,,
	Penang—Singapore		1447·17	120	175	9·518	·5870	1·304	11·521										
	,, ,,		—	,,	,,	2·696	·1080	·443	3·375										Shore-ends.
	,, ,,		—	,,	,,	2·761	·1220	·385	3·397	92	304	·54530	10·508	94·55	235	1176	0·3400	·0680	Intermediate
	Penang—Madras		387	120	175	5·113	·2730	·810	6·331										Main Cable.
	,, ,,		—	,,	,,	1·099	·0666	·247	1·541										Shore-ends.
16	China Telegraph		1632	107	140	9·514	·6660	1·371	11·412										Main Cable.
	,, ,,		—	,,	,,	2·831	·1030	·443	3·286	—	—	—	11·843	—	200	—	0·2856	—	Shore-ends. Willoughby
	,, ,,		—	,,	,,	1·913	·2590	·459	2·712										Intermediate. Smith's Core.
																			Main Cable.

TABLE XVIII.—(*continued*).

MECHANICAL AND ELECTRICAL DATA OF VARIOUS RECENT SUBMARINE TELEGRAPH CABLES.

	Cable.	Date.	Length laid.	Weight per Knot.						Diameter.			Resistance of Conductor at 24° Cent.		Resistance of Dielectric at 24° Cent.		Electro-static capacity.		Remarks.
				Copper.	Gutta Percha.	Iron.	Hemp.	Asphalt.	Complete.	Copper, *d*.	Core, *D*.	Logarithm of $\frac{D}{d}$ (approx.).	Resistance per knot.	Specific Conductivity, Pure Copper = 100.	Resistance per knot.	Specific Resistance.	Electro-static Capacity per knot.	Specific Inductive Capacity.	
			Knots.	Lbs.	Lbs.	Tons.	Tons.	Tons.	Tons.	Mils.	Mils.		Ohms.		Meg-ohms.	Meg-ohms.	Micro-farads.	Micro-farads.	
17	British Australian	1870																	
	Batavia—Singapore		579	107	140	9·514	·6660	1·371	11·665										Shore-ends.
	,, ,,		—	,,	,,	2·831	·1030	·443	3·490										Main Cable. Willoughby Smith's Core.
	Batavia—Port Darwin		—	107	140	9·514	·6660	1·371	11·665	—	—	—	10·907	91·20	194	970	0·2920	·0584	Shore-ends.
	,, ,,		—	,,	,,	1·193	·1070	·393	1·796										Main Cable
18	Persian Gulf	1868	525	225	200	3·060	—	—	3·730	110	309	·46125	5·600	93·64	3900	2580	0·3490	·0528	
19	Anglo-Danish	1868	365	180	180	2·400	—	—	3·000	110	290	·43410	7·060	93·82	4430	2780	0·3680	·0585	
20	Anglo-Norwegian	1869	240	180	180	2·400	—	—	3·000	110	290	·43410	7·060	93·82	4500	2780	0·3680	·0585	
21	Moen—Bandholm	1869	82	90	130	—	—	—	—	80	241	·50373	14·370	92·19	4000	2170	0·3120	·0576	
22	Aland	1869	87	180	180	2·400	—	—	3·000	110	290	·43410	7·060	93·82	4500	2780	0·3680	·0585	
23	Shetland	1869	69	90	130	1·040	·1450	·2600	1·640	80	241	·50373	14·370	92·19	4000	2170	0·3120	·0576	
			9	180	180	6·000	·2500	·4500	6·950	110	290	·43410	7·060	92·82	3890	2440	0·3690	·0587	
24	North China	1870																	Hooper's India Rubber.
	Hong Kong & Shanghai		685	300	200	1·100	—	—	1·500										Section A
	,, ,,		272	,,	,,	2·100	—	—	3·000										,, B
	,, ,,		111	,,	,,	6·600	—	—	8·000										,, C
	,, ,,		30	,,	,,	1·520	—	—	18·000										,, D
	Shanghai and Posietta		920	300	200	1·100	—	—	1·500	147	318	·36169	4·230	93·96	4000	3020	0·4400	·0583	,, A
	,, ,,		92	,,	,,	2·400	—	—	3·000										,, B
	,, ,,		96	,,	,,	6·600	—	—	8·000										,, C
	,, ,,		20	,,	,,	1·520	—	—	18·000										,, D
	Furnished by Mr. LATIMER CLARK.																		
25	Channel Islands	1870																	
	Dartmouth—Guernsey		66·6	70	95	—	—	—	—	—	—	—	—	—	250				
	Jersey—Guernsey, No. 1		17·50	107	150	—	—	—	—	87	282	·53655	11·51	96·8					
	Guernsey—Jersey, No. 2		16·00	70	95	—	Including Tape wrapping	—	—	—	—	—	—	—	250				
	Guernsey—Alderney		18·65	107	150	—		—	—	87	282	·53655	11·51	96·8					
26	Holyhead and Howth	1871	20·00	107	150	15·00	1·000	2·2000	19·000	87	282	·53655	11·516	96·8	502	3442	·4049	—	Shore-ends 7 conductors.*
	,, ,,	1871	37·87	,,	,,	10·70	·750	1·4500	13·760	,,	,,	,,	,,	,,	,,	,,	,,	—	Main Cable. Ditto.*

* Each wire of sheath separately covered with two servings of tape saturated with compound.

WHEATSTONE'S AUTOMATIC SYSTEM.

FIG. 3.

COPPER TO EARTH.
ZINC TO LINE.

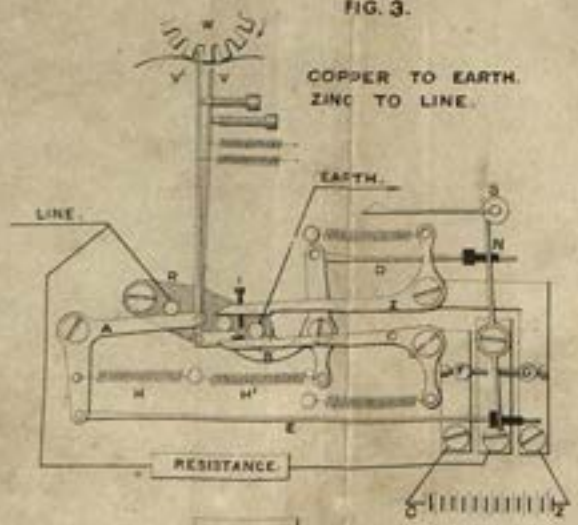


FIG. 1.

NEUTRAL POSITION.

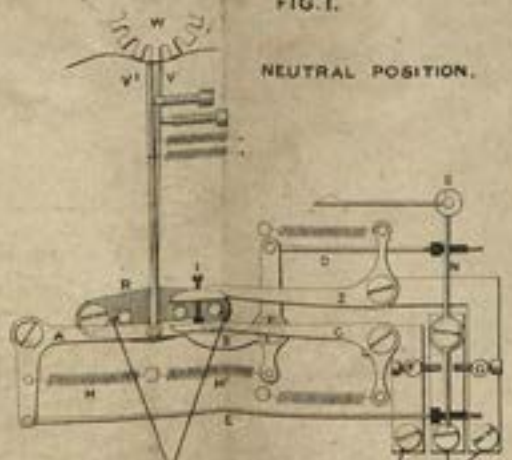
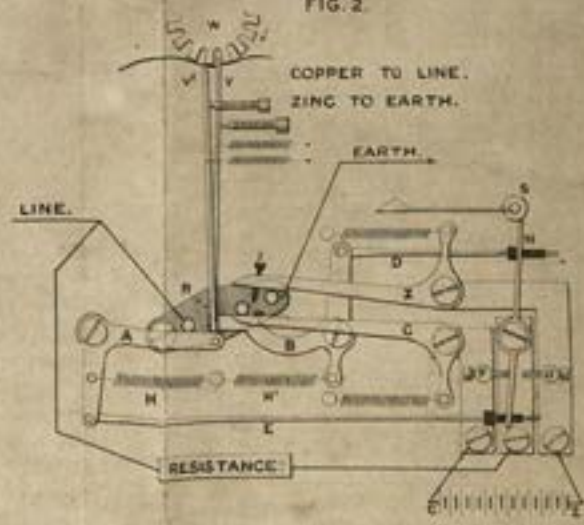
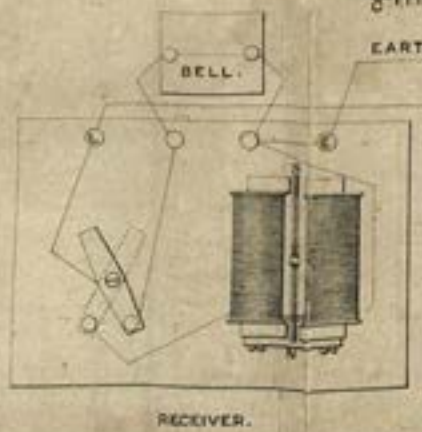
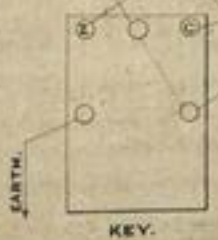


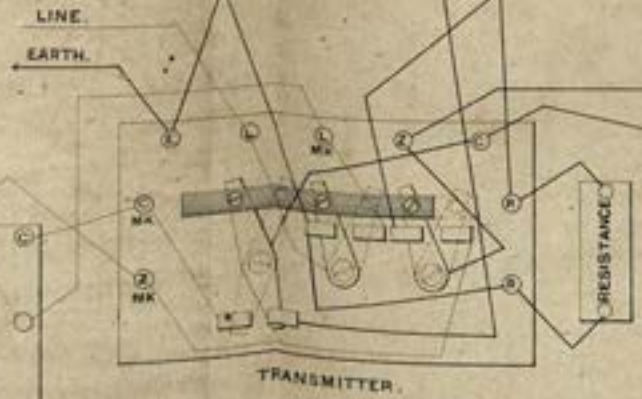
FIG. 2.

COPPER TO LINE.
ZINC TO EARTH.









TRANSMITTER CIRCUIT. _____

RECEIVER AND KEY Dº _____

WHEATSTONE'S AUTOMATIC SYSTEM.

FIG. 1.

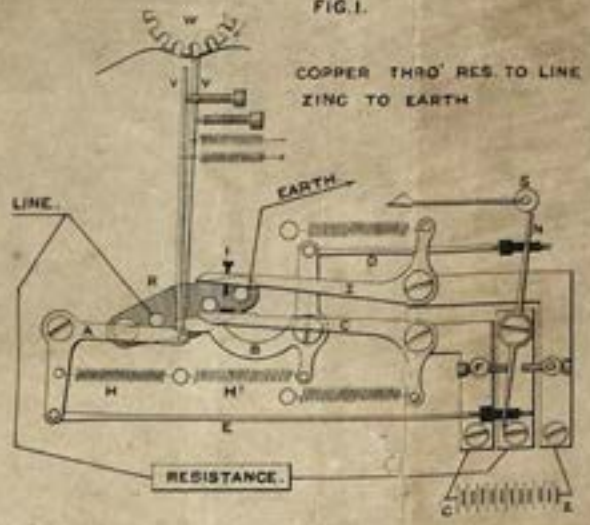


FIG 2.

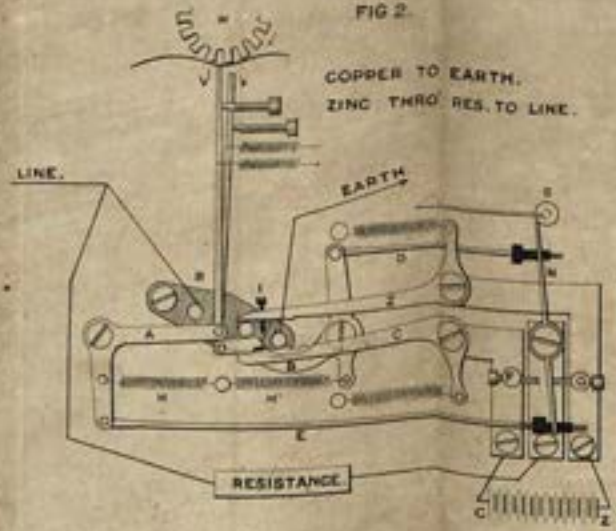


FIG 3.

FIG. 4.

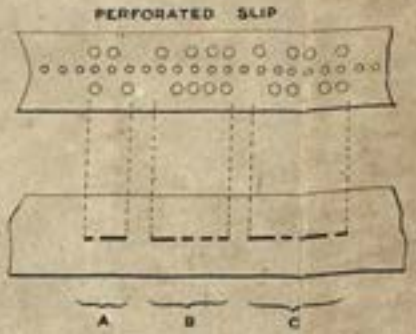
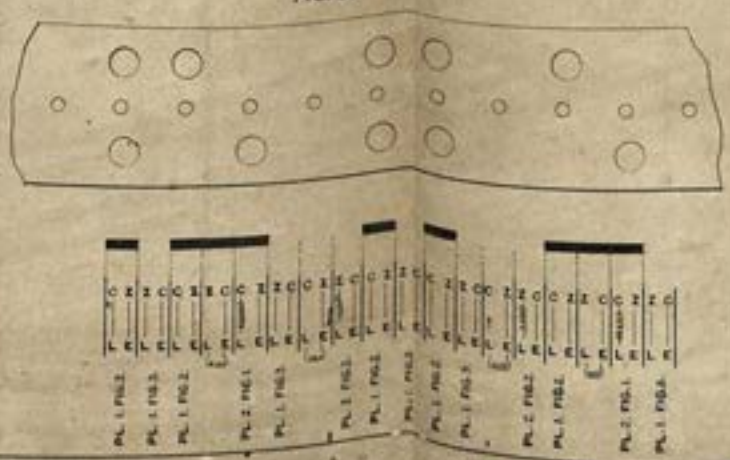


FIG. 5.



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